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# The use of sphere gaps at radio frequencies.

Oler, Charles Benjamin

Johns Hopkins University

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USE OF SPHERE GAPS AT  
RADIO FREQUENCIES

BY  
CHARLES B. OLER

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THE USE OF SPHERE GAPS AT  
RADIO FREQUENCIES

by

Charles B. Oler  
"

A Dissertation

Submitted to

The Board of University Studies

of

The Johns Hopkins University

in conformity with the requirement  
for the Degree of Doctor of Engineering

Baltimore 1950



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# CONTENTS

	Page
I. INTRODUCTION	1
II. THE SPHERE GAP AS A MEASURING INSTRUMENT	2
1. Use of Sphere Gaps at Power Frequencies	2
2. Theory of Spark-over	4
3. Effects of Irradiation	4
4. Use of Sphere Gaps for High Frequencies	5
III. EXPERIMENTAL WORK	6
1. The Vacuum-tube Voltmeter	6
2. Calibration of Voltmeter	11
3. Source of Test Voltage	18
4. The Sphere Gaps	18
5. Source of Irradiation	21
6. Testing Procedure	21
IV. EXPERIMENTAL RESULTS.	22
V. DISCUSSION OF RESULTS.	28-40
VI. CONCLUSIONS	41
VII. APPENDIX A.	43
1. Calculation of Optimum Breakdown Frequency.	43
2. Calculations of Ion Mobility	44
VIII. APPENDIX B - DATA	46
IX. BIBLIOGRAPHY	66
X. ACKNOWLEDGMENTS	69
XI. VITA	70

1	INTRODUCTION	1
2	THE STATE OF A NATION'S ECONOMY	2
3	1. The of State and of State Economy	3
4	2. Theory of State Economy	4
5	3. Theory of State Economy	5
6	4. The of State and of State Economy	6
7	CONSTITUTIONAL LAW	7
8	1. The theory of State Economy	8
9	2. Calculation of State Economy	9
10	3. Theory of State Economy	10
11	4. The theory of State Economy	11
12	5. Theory of State Economy	12
13	6. Theory of State Economy	13
14	7. Theory of State Economy	14
15	8. Theory of State Economy	15
16	9. Theory of State Economy	16
17	10. Theory of State Economy	17
18	11. Theory of State Economy	18
19	12. Theory of State Economy	19
20	13. Theory of State Economy	20
21	14. Theory of State Economy	21
22	15. Theory of State Economy	22
23	16. Theory of State Economy	23
24	17. Theory of State Economy	24
25	18. Theory of State Economy	25
26	19. Theory of State Economy	26
27	20. Theory of State Economy	27
28	21. Theory of State Economy	28
29	22. Theory of State Economy	29
30	23. Theory of State Economy	30
31	24. Theory of State Economy	31
32	25. Theory of State Economy	32
33	26. Theory of State Economy	33
34	27. Theory of State Economy	34
35	28. Theory of State Economy	35
36	29. Theory of State Economy	36
37	30. Theory of State Economy	37
38	31. Theory of State Economy	38
39	32. Theory of State Economy	39
40	33. Theory of State Economy	40
41	34. Theory of State Economy	41
42	35. Theory of State Economy	42
43	36. Theory of State Economy	43
44	37. Theory of State Economy	44
45	38. Theory of State Economy	45
46	39. Theory of State Economy	46
47	40. Theory of State Economy	47
48	41. Theory of State Economy	48
49	42. Theory of State Economy	49
50	43. Theory of State Economy	50
51	44. Theory of State Economy	51
52	45. Theory of State Economy	52
53	46. Theory of State Economy	53
54	47. Theory of State Economy	54
55	48. Theory of State Economy	55
56	49. Theory of State Economy	56
57	50. Theory of State Economy	57
58	51. Theory of State Economy	58
59	52. Theory of State Economy	59
60	53. Theory of State Economy	60
61	54. Theory of State Economy	61
62	55. Theory of State Economy	62
63	56. Theory of State Economy	63
64	57. Theory of State Economy	64
65	58. Theory of State Economy	65
66	59. Theory of State Economy	66
67	60. Theory of State Economy	67
68	61. Theory of State Economy	68
69	62. Theory of State Economy	69
70	63. Theory of State Economy	70
71	64. Theory of State Economy	71
72	65. Theory of State Economy	72
73	66. Theory of State Economy	73
74	67. Theory of State Economy	74
75	68. Theory of State Economy	75
76	69. Theory of State Economy	76
77	70. Theory of State Economy	77
78	71. Theory of State Economy	78
79	72. Theory of State Economy	79
80	73. Theory of State Economy	80
81	74. Theory of State Economy	81
82	75. Theory of State Economy	82
83	76. Theory of State Economy	83
84	77. Theory of State Economy	84
85	78. Theory of State Economy	85
86	79. Theory of State Economy	86
87	80. Theory of State Economy	87
88	81. Theory of State Economy	88
89	82. Theory of State Economy	89
90	83. Theory of State Economy	90
91	84. Theory of State Economy	91
92	85. Theory of State Economy	92
93	86. Theory of State Economy	93
94	87. Theory of State Economy	94
95	88. Theory of State Economy	95
96	89. Theory of State Economy	96
97	90. Theory of State Economy	97
98	91. Theory of State Economy	98
99	92. Theory of State Economy	99
100	93. Theory of State Economy	100

## INTRODUCTION

The sphere gap has for many years been an accepted method for the measurement of high voltage at power frequencies<sup>(1,2)</sup> and also for impulse testing. It is not however, at present an accepted standard for the measurement of high voltages at radio frequencies. This is largely due to the lack of published data on the spark-over values of sphere gaps in air at radio frequencies. There has been some work published in this field<sup>(3,4,5,6)</sup>, but the results are not altogether consistent and the spectrum of frequencies covered is far from complete.

The purpose of this study is to evaluate the possibility of using sphere gaps for the measurement of moderately high voltages, - up to 20 kilovolts peak -, in the frequency range from 500 kilocycles to 15 megacycles. To accomplish this, a peak-reading vacuum-tube voltmeter, with associated capacitance-divider, was constructed and calibrated, and employed to determine the spark-over values of sphere gaps in air at these frequencies.

The results indicate that the sphere gap, if irradiated, may be used for the measurement of voltages in the ranges of magnitude and frequency considered. Consistent results show a break-down strength for air, at these frequencies, which is 80-85% of that at power frequencies. This is in general

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(1,2) For numbered references see bibliography.



The above can be for some years as a general  
method for the measurement of this voltage at some distance  
also (1.2) and also for similar testing. It is not correct,  
at present as a method of testing for the measurement of high  
voltage at some distance. This is largely due to the  
lack of sufficient data on the short-circuit value of voltage  
also in the at some distance. There has been some work  
published in this field (1.4, 1.5), but the results are not  
altogether consistent and the question of frequency covered  
is not clear.

The purpose of this work is to provide the conditions  
of which should be for the measurement of voltage at high  
voltage, - as to 50 kilovolts and - in the frequency  
range from 50 kilohertz to 10 megahertz. It is assumed  
that, a good working knowledge of voltage, with associated  
equipment, can be constructed and utilized, and so  
placed in relation to the short-circuit value of voltage and in  
the at some distance.

The results indicate that the above can, if provided,  
may be used for the measurement of voltage in the range of  
megahertz and frequency considered. Detailed results show  
a broad range of the at some distance, which is  
10-15 at 50 kilohertz. This is in general

agreement with the somewhat meagre data that has been published. (3,4,5,6) The results are shown in the curves, pages 28 to 33.

The possibility of using a rod gap was also investigated. These results are less encouraging, and are shown in the curves, pages 34 to 37.

#### THE SPHERE GAP AS A VOLTAGE- MEASURING INSTRUMENT

##### Use of Sphere Gaps at Power Frequencies:

The measurement of very high voltages, at power frequencies, can be accomplished readily and with considerable accuracy by the use of sphere gaps. The American Standards Association publication C 68.1 - 1942<sup>(1)</sup>, sponsored by the American Institute of Electrical Engineers, gives tabulated values of spark-over voltage in air, for spheres of various diameters and spacings. Voltages up to 2,000 kilovolts peak are covered. A simple correction for air density must be made, because the dielectric strength of air is a function of its density. Within the range of air densities normally encountered near sea level, this variation is practically linear. The tabulated spark-over voltages are for the standard density conditions corresponding to a barometric pressure of 760 millimeters of mercury and a temperature of 25° Centigrade. According to this publication, no correction need be made for humidity, although there is some published data<sup>(7)</sup> indicating that humidity has a slight effect.

(b) (7)(C), (D)

the possibility of being a red was also denied.

[illegible]



The axial field between spheres can be calculated (2,8), and with a knowledge of the break-down strength of air, the spark-over voltage for spheres of arbitrary diameter and specified gap spacing can therefore be calculated. The agreement between calculated and observed values is quite good<sup>(8)</sup>, and enhances the use of sphere gaps for measuring voltage. It should be noted, however, that the sphere gap is a crest, or peak-reading device.

The field intensity along the axial line between the spheres is not uniform, being a maximum at the sphere surfaces and a minimum midway across the gap. Furthermore, if one sphere is grounded, which in practice is very often the case, the field intensity is somewhat distorted, placing greatest stress at the surface of the ungrounded sphere. However, these effects are not serious if the gap spacing is small compared to the sphere diameter. It is customary to choose spheres of sufficiently large diameter to fulfill this condition.

Although the gap spacing is quite critical in determining the spark-over voltage, the diameter of the spheres is not. For example, the 60-cycle crest voltages listed for a gap spacing of 1 cm. are 31,300 for 6.25 cm. spheres, and 31,700 for 12.5 cm. spheres.

The sphere-gap as a voltage-measuring device suffers the disadvantage that the breakdown of the gap imposes practically a short circuit on the voltage source being measured.



The total field intensity between can be calculated (1,8)

and also a calculation of the distribution of the  
space-charge voltage for spheres of arbitrary diameter and  
position. The results are given in the following table. The  
agreement between calculated and observed values is within  
5%, and indicates the use of spheres and the assumption  
of uniform field intensity. However, the field is not  
uniform, but the results are  
in a very good agreement.

The field intensity along the central line between the  
spheres is not uniform, being a function of the sphere  
radius and a maximum value occurs for the separation. It  
was found in practice that in practice is very often the  
case, the field intensity is somewhat distorted, giving  
greater values at the surface of the separated spheres.  
However, these effects are not serious in the two spheres  
is well covered by the sphere diameter. It is customary  
to choose values of sufficiently large diameter to fulfill  
this condition.

Although the gap between the spheres is relatively  
large the space-charge voltage, the diameter of the spheres is  
small. For example, the 50-ohm gap voltage listed for a  
gap spacing of 1 cm. are 11,700 for 0.5 cm. spheres, and  
11,700 for 0.5 cm. spheres.

The sphere gap as a voltage-measuring device will give  
the advantage that the spacing of the gap spheres can  
be easily changed on the voltage source being measured.

It is noted that the results are in good agreement with the

For this reason it is customary to connect a fairly high resistance in series with the gap.

### Theory of Spark-over:

The generally accepted theory of the spark-over of a gap<sup>(9,10,11,12)</sup> postulates that electrons existing in the gap are attracted toward the anode, and if the field intensity is great enough, they acquire sufficient energy during the traverse of a mean-free-path to ionize an atom on collision. This produces more electrons, and an avalanche is formed, which is spear-headed toward the anode, and leaves in its trail a highly-ionized column of air. The velocity of this process has been studied by many investigators<sup>(9,18)</sup> and found to be of the order of  $10^8$  centimeters per second, which is greater than can be accounted for by the mobility of the electrons. Consequently it is believed that the ionized body of the avalanche emits light photons, some of which cause ionization in advance of the avalanche.<sup>(9)</sup> Spark-over occurs when this action completely bridges the gap.

### Effects of Irradiation:

The initiation of the spark-over mechanism requires the existence of one or more electrons in the gap. There is therefore some uncertainty in the value of voltage at which a gap will spark over, unless the voltage is maintained for a reasonable time. In other words, there is an unpredictable time lag in the process. To reduce this uncertainty, it is often the practice to irradiate the sphere gap. using ultra-

For this reason, if the frequency of removal is fairly high

[illegible]

often the practice to facilitate the return of the vessel to the port of origin. The vessel is then taken to the port of origin and the cargo is unloaded. The vessel is then taken to the port of origin and the cargo is unloaded. The vessel is then taken to the port of origin and the cargo is unloaded.



violet light, X-rays, or emissions from radio-active materials. This guarantees a generous supply of electrons in the gap, reduces the spark-over time lag, and improves the consistency of the observed values of spark-over voltages.

Irradiation generally lowers the spark-over values<sup>(7,13,14,15,16)</sup>. At power frequency, irradiation is usually considered necessary only for short gaps.

#### Use of Sphere Gaps for High Frequencies:

Some modification of practice and theory is needed when the sphere gap is used at high frequencies. In the first place, spheres of large diameter are unsuitable because of the charging current they would draw prior to spark over. For example, even 6.25 centimeter spheres spaced 0.5 centimeter apart would draw several amperes charging current at 10 megacycles with 10 Kv (rms) applied. Hence small spheres are practically necessary, and since sphere gaps cannot be employed with much reliability at gap spacings greater than the sphere diameter, it is evident that this limits their use, at high frequencies, to moderately high voltages. Also because of the appreciable charging currents, the use of high resistances in series with the gap will lead to inaccuracies.

Secondly, irradiation is more necessary at high frequencies. At 10 megacycles, a sine wave attains 95% or more of its crest value for only  $10^{-8}$  second during each half-cycle. Hence time lags in the spark-over could lead to results much more erratic than those at power frequencies.

It is not possible to give a complete description of the system in a few words. The system is a complex of many parts, and the description of each part would require a separate volume. The system is designed to be flexible and adaptable to changing requirements. It is a system of systems, and each system is designed to be self-contained and capable of operating independently. The system is a product of many years of research and development, and it is a testament to the ingenuity and creativity of the people who designed it. The system is a product of the American people, and it is a source of pride and honor for all of us.

Use of Tobacco Cuts the Risk

These conditions of weather and light is needed when the system is used at high frequencies. In the first place, the system of large diameter and variable pressure of the charging current that would have to be used even for small, even 5.5 kilowatt tubes, would be 0.5 megavolts with very great energy absorption in the anode. It is necessary to use a small diameter tube, and this is not possible, and also when the current is used, it is not possible to use the system for more than a few minutes at a time. It is evident that this system is not, at high frequencies, so suitable for use as the system of the variable charging current, the use of which is necessary in order that the system can be used.

Secondly, crystallization is more necessary at high temperatures. At 50 degrees, a solid will crystallize 75% or more of its weight volume for only 10<sup>-5</sup> second during each half-cycle. Below this rate in the super-cooled would lead to

Theoretical studies indicate that the "avalanche" picture of the dielectric breakdown of a gas will hold so long as the electrons encounter many collisions per cycle of applied voltage.<sup>(21)</sup> But if the frequency and the gaseous pressure are such that the electrons experience many cycles of voltage between collisions, then a somewhat different theory of breakdown is postulated. The minimum dielectric strength of the gas occurs during transition from one situation to the other; that is, when an electron would experience about one collision per cycle of applied voltages. This minimum has been experimentally verified for gases at low pressures, using high frequency fields.<sup>(22,25)</sup> However, a rough calculation based on the classical value for the mean-free-path of an electron, indicates that for air at atmospheric pressure this minimum would occur at a frequency of the order of  $10^{11}$  cycles per second. (See Appendix A). Hence theoretical considerations of spark-over in air, at radio frequencies or even at ultra-high frequencies, may be based on the "avalanche" theory outlined above.

#### EXPERIMENTAL WORK

##### The Vacuum-Tube Voltmeter:

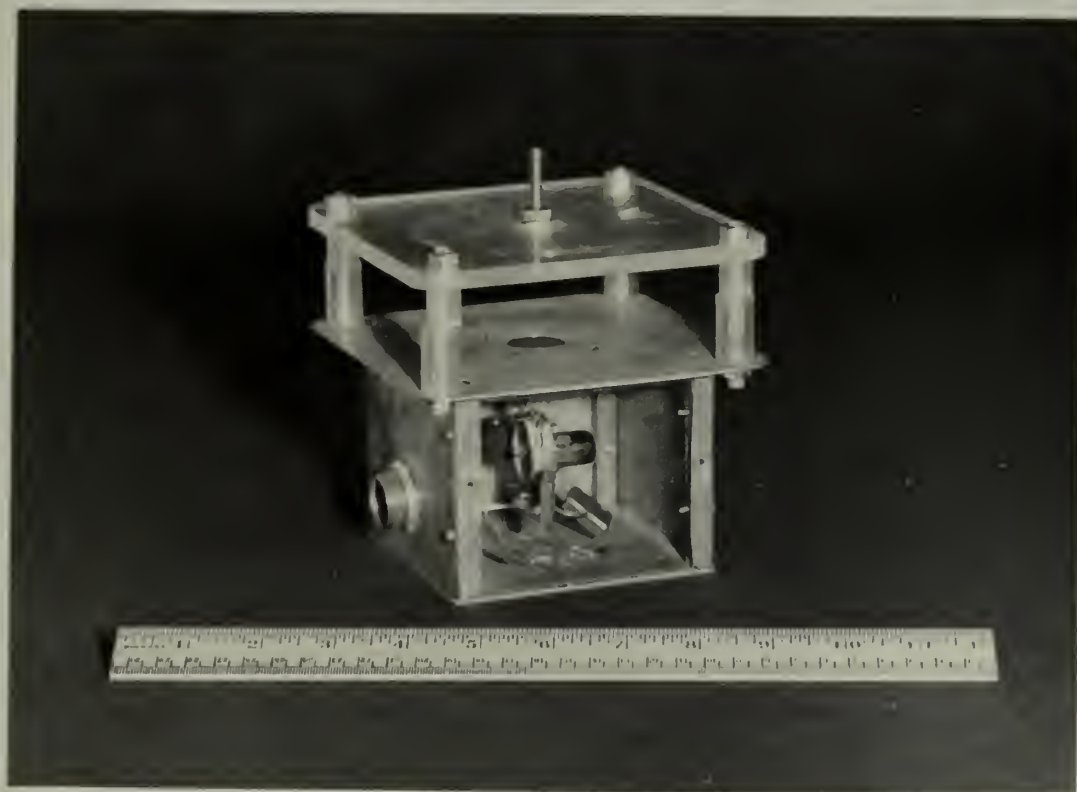
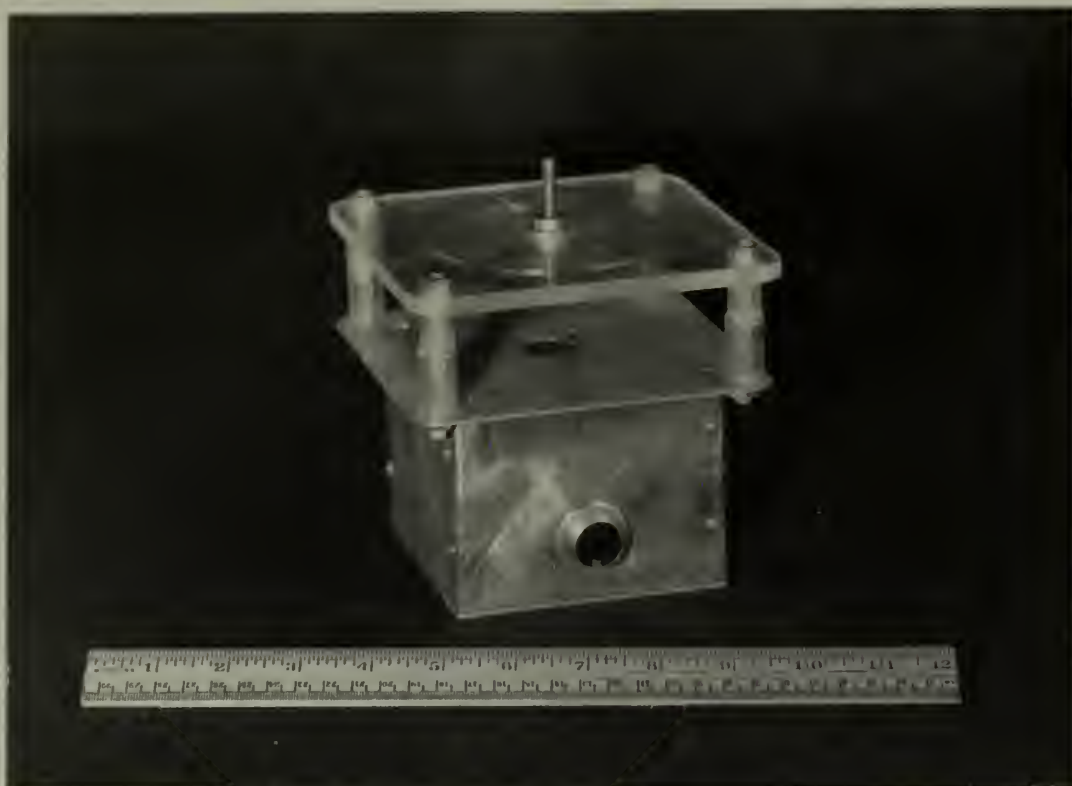
To test the performance of sphere gaps at high frequencies, it was first necessary to devise a suitable method for measuring accurately the voltages involved. For this purpose a vacuum-tube voltmeter with associated capacitance-divider was constructed. It is shown in the photograph on



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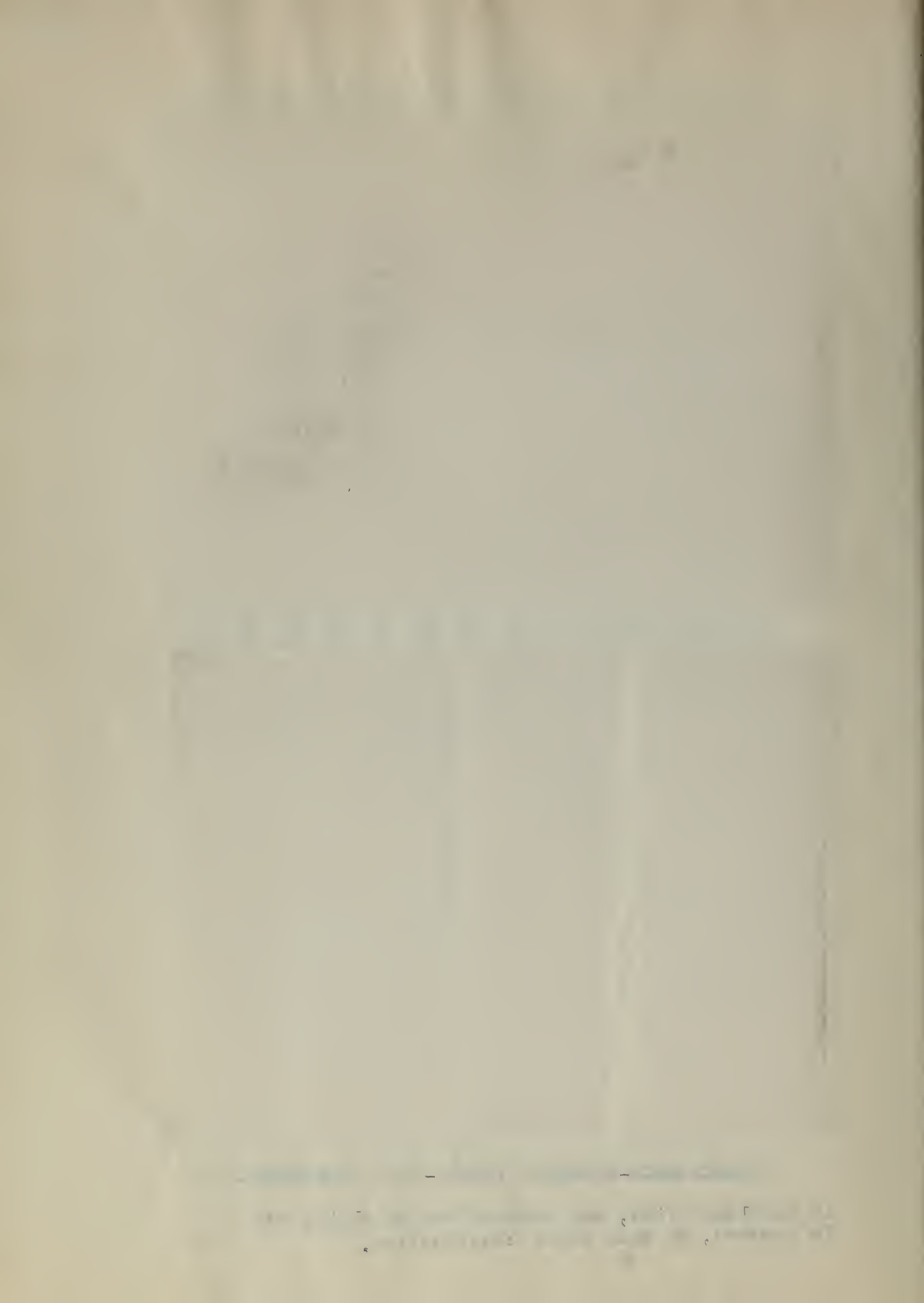
was conducted. It is shown in the discussion on



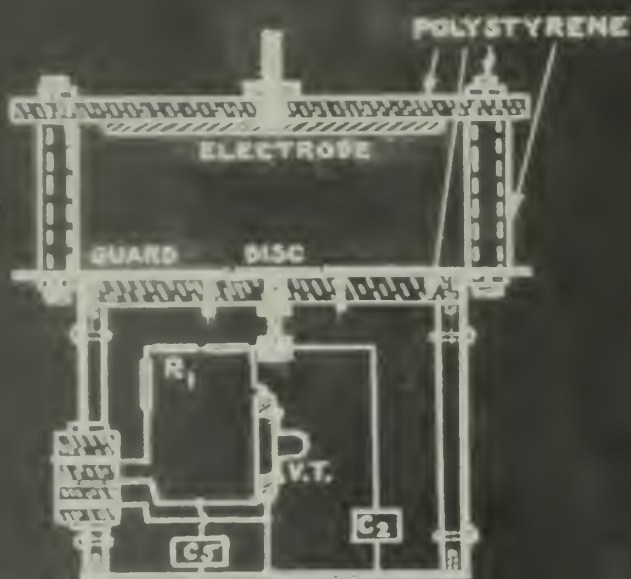
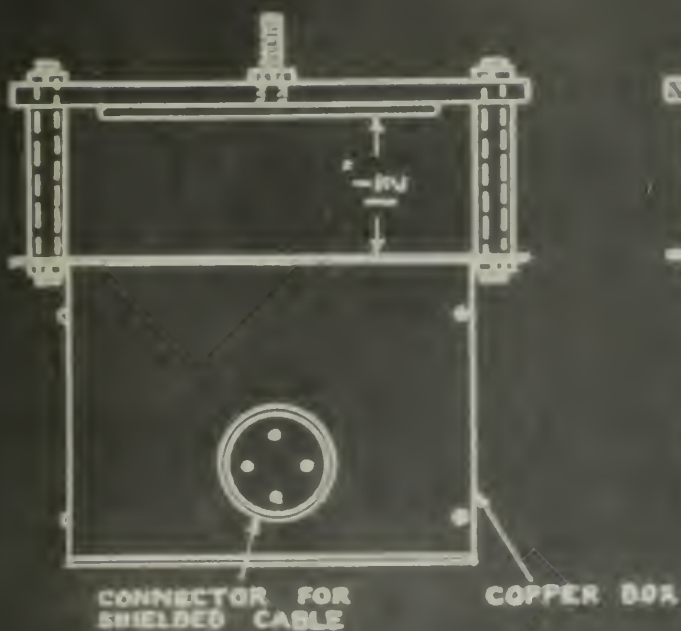
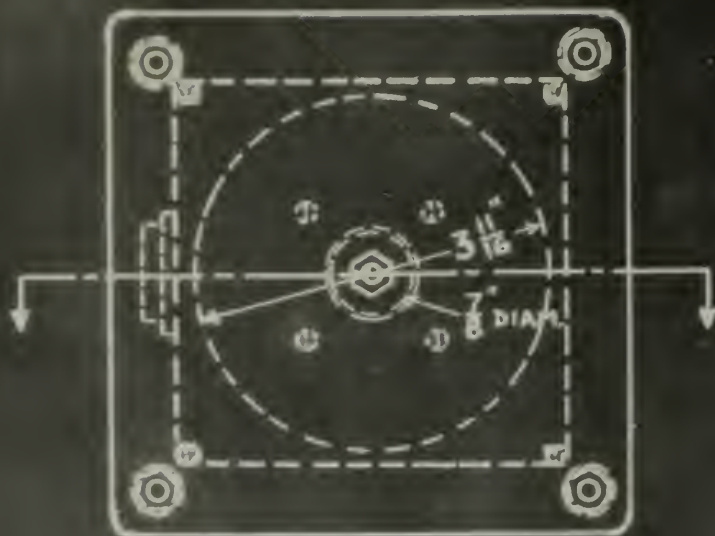
CAPACITANCE-DIVIDER VACUUM-TUBE VOLTMETER

In the lower view, one side of the shielding box is removed, to show inner construction.





1/2 SIZE



# CAPACITANCE - DIVIDER VACUUM - TUBE - VOLTMETER

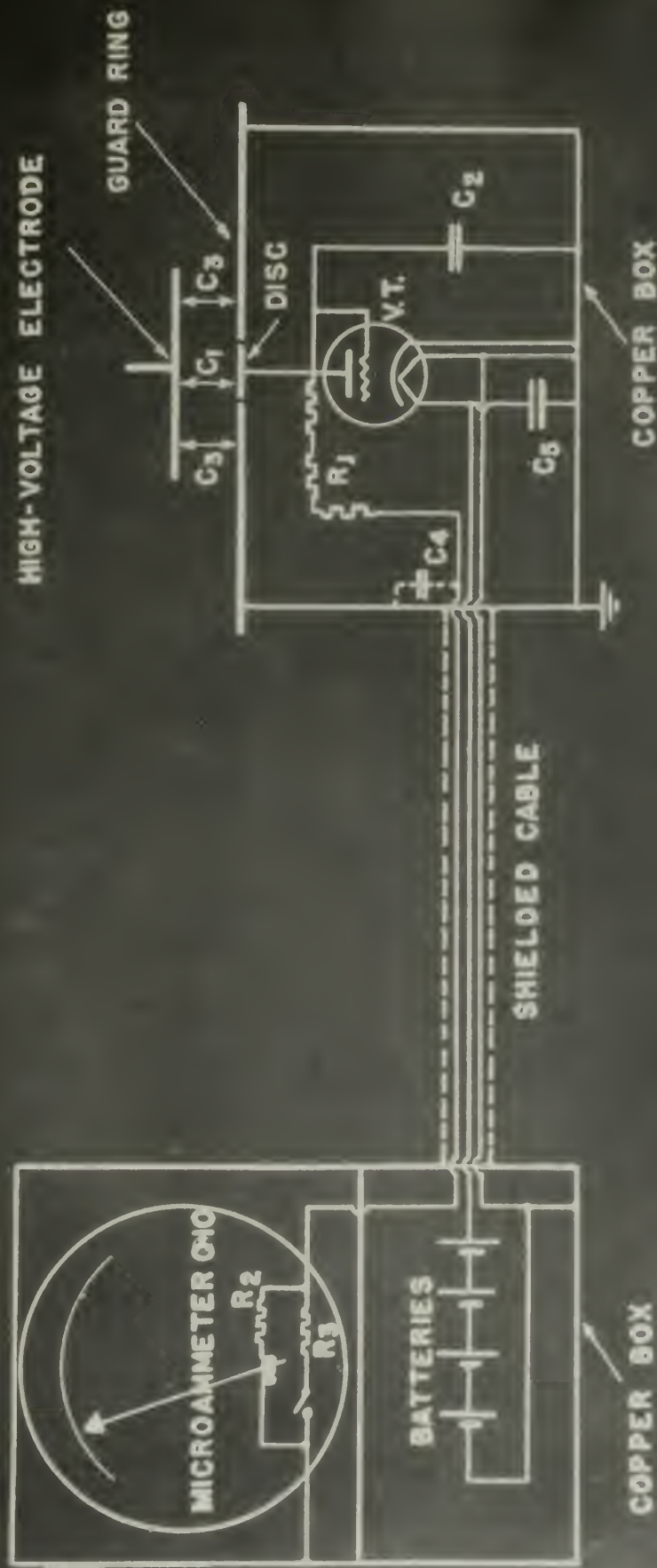


and by the drawings on page 8. The schematic circuit appears on page 10. The capacitance-divider comprises  $C_1$  and  $C_2$ .  $C_1$  is an air capacitance formed between the high-voltage electrode and the small disc, which is surrounded by a guard ring. The Value of  $C_1$  is calculated from its dimensions to be  $0.093 \mu\mu\text{F}$ .  $C_2$  consists of two small mica capacitors having nominal ratings of  $5 \mu\mu\text{F}$ . and  $20 \mu\mu\text{F}$ ., connected in parallel, plus the capacitance to ground of the disc and the necessary connections. The value of  $C_2$  was measured and found to be  $33 \mu\mu\text{F}$ ., over a range of frequencies from 500 kilocycles to 15 megacycles.  $C_3$  is the capacitance formed by the high voltage electrode and the guard ring. It is about  $5 \mu\mu\text{F}$ .  $C_4$  represents the distributed capacitance to ground of 5 feet of shielded cable. It measures  $335 \mu\mu\text{F}$ .  $C_5$  is a  $2000 \mu\mu\text{F}$ . by-pass capacitor.

The vacuum tube is a type 955 acorn tube, with grid and plate connected together, to form a diode rectifier.  $R_1$  consists of three miniature type resistors in series, each rated at 1 megohm. These are type MPM resistors, manufactured by International Resistance Co. for high-frequency receivers and similar applications. At 500 kilocycles, the susceptance of  $C_2$  is about 300 times the conductance of  $R_1$  which parallels it, so the capacitance divider does not suffer frequency distortion in the range of frequencies considered. Furthermore, the time constant of  $R_1 C_2$  is about 100 microseconds, permitting the voltage across  $C_2$ , at 500 kilocycles, to average 99% of its peak value. Hence this capacitance-divider vacuum-



and by the variation in  $\alpha$ . The calculated critical frequency  
on page 10. The experimental-critical frequency  $f_c$  and  $f_{cr}$   
is in its dependence (found before the high-voltage elec-  
trode and the wall film, which is accompanied by a sound wave.  
The value of  $f_c$  is calculated from the dimensions as be-  
fore.  $f_{cr}$  consists of two wall film resonances  $f_{w1}$  and  
the critical value of  $f_{w2}$  and  $f_{w3}$  is calculated  
in parallel, for the dependence in terms of the film and  
the frequency resonance. The value of  $f_c$  was measured and  
found to be  $20 \mu\text{m}^{-1}$  over a range of frequencies from 100  
kilohertz to 10 megahertz.  $f_c$  is the resonance found in  
the high voltage electrode and the sound wave. It is about  
 $20 \mu\text{m}^{-1}$ . The resonance was calculated separately in  
terms of  $f_c$  and critical value. It was about  $20 \mu\text{m}^{-1}$ .  
 $f_c$  is a  $20 \mu\text{m}^{-1}$  resonance.  
The reason this is a type 100 sound wave, with  $f_{cr}$  and  
critical resonance frequency, is that a sound wave,  $f_c$  and  
value of  $f_{cr}$  is about 100 times the resonance of  $f_c$  and  
of  $f_{cr}$  is about 100 times the resonance of  $f_c$  and  
experimental resonance. For high-frequency resonance and  
critical resonance. At 100 kilohertz, the resonance of  
 $f_c$  is about 100 times the resonance of  $f_c$  and parallel  
it, so the resonance value does not differ frequency dis-  
tortion in the range of frequencies considered. Therefore,  
the resonance of  $f_c$  is about 100 kilohertz, and  
critical resonance is about 100 kilohertz, is about  
100 of the wall film. Below this resonance-critical value



SCHEMATIC DIAGRAM OF CAPACITANCE-DIVIDER  
VACUUM-TUBE VOLTMEETER



tube voltmeter should have a flat frequency response in the range of frequencies considered. This is borne out by the calibration data.

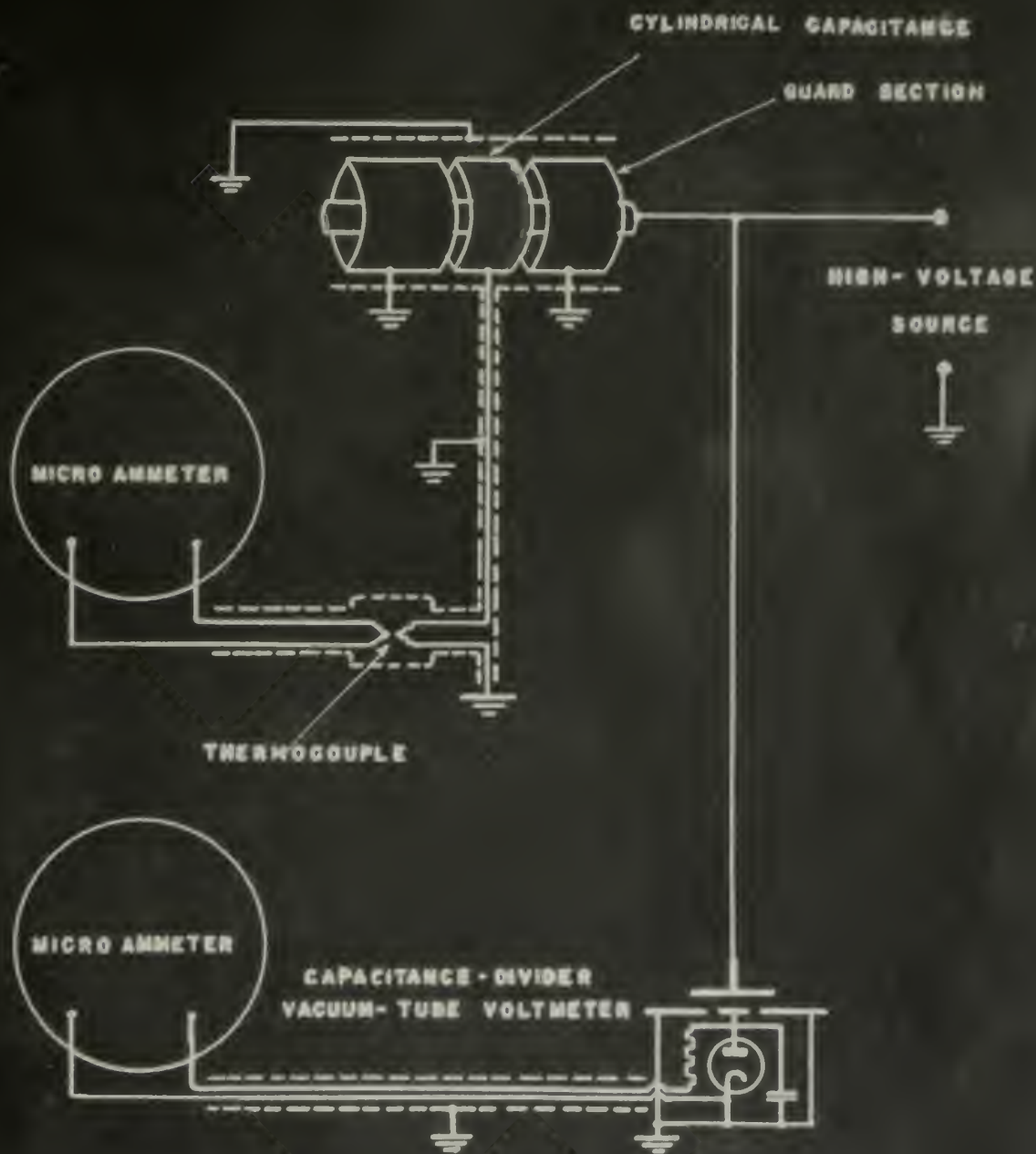
$R_2$  is the resistance of the microammeter, plus some wire-wound resistance units, and is 63.600 ohms.  $R_3$  is a resistance of 40,100 ohms which can be shunted across the microammeter, thus increasing the range of the voltmeter by a factor of 2.62. The microammeter was originally a General Electric Co., type DP9, 0 to 3 voltmeter having 300,000 ohms resistance. Most of the internal resistance is removed, and it is used as a 0-10 microammeter. It has a scale length of 4 inches, with an accuracy of 1/2% of full scale. Four 1-1/2 volt flashlight cells are used for the vacuum-tube filament supply.

#### Calibration of Voltmeter:

Calibration of the voltmeter over a considerable range of frequencies, was accomplished by simultaneous readings of the voltmeter and of the current drawn by a guard-ring type cylindrical capacitor, when these were both connected to the high voltage source. A schematic diagram of this set-up appears on page 12. The cylindrical capacitor current was measured by a thermocouple and associated microammeter, previously calibrated on direct current. The direct current calibration curve appears on page 13. The thermocouple is a Western Electric Co. vacuum type No. 5C having a nominal rating of 75 milliamperes and a heater resistance of 5 ohms.



[illegible]

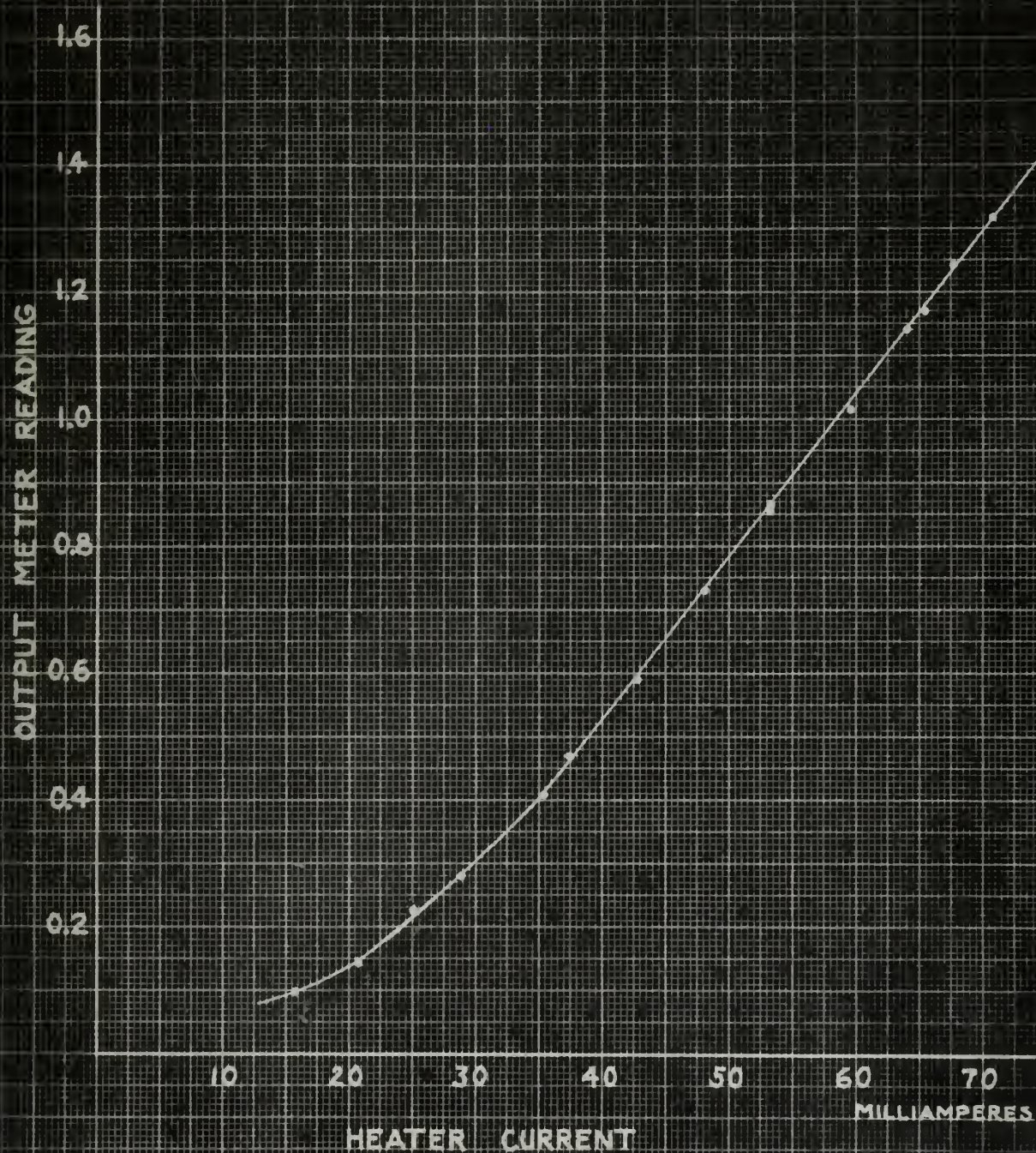


SCHEMATIC DIAGRAM OF CALIBRATION CIRCUIT





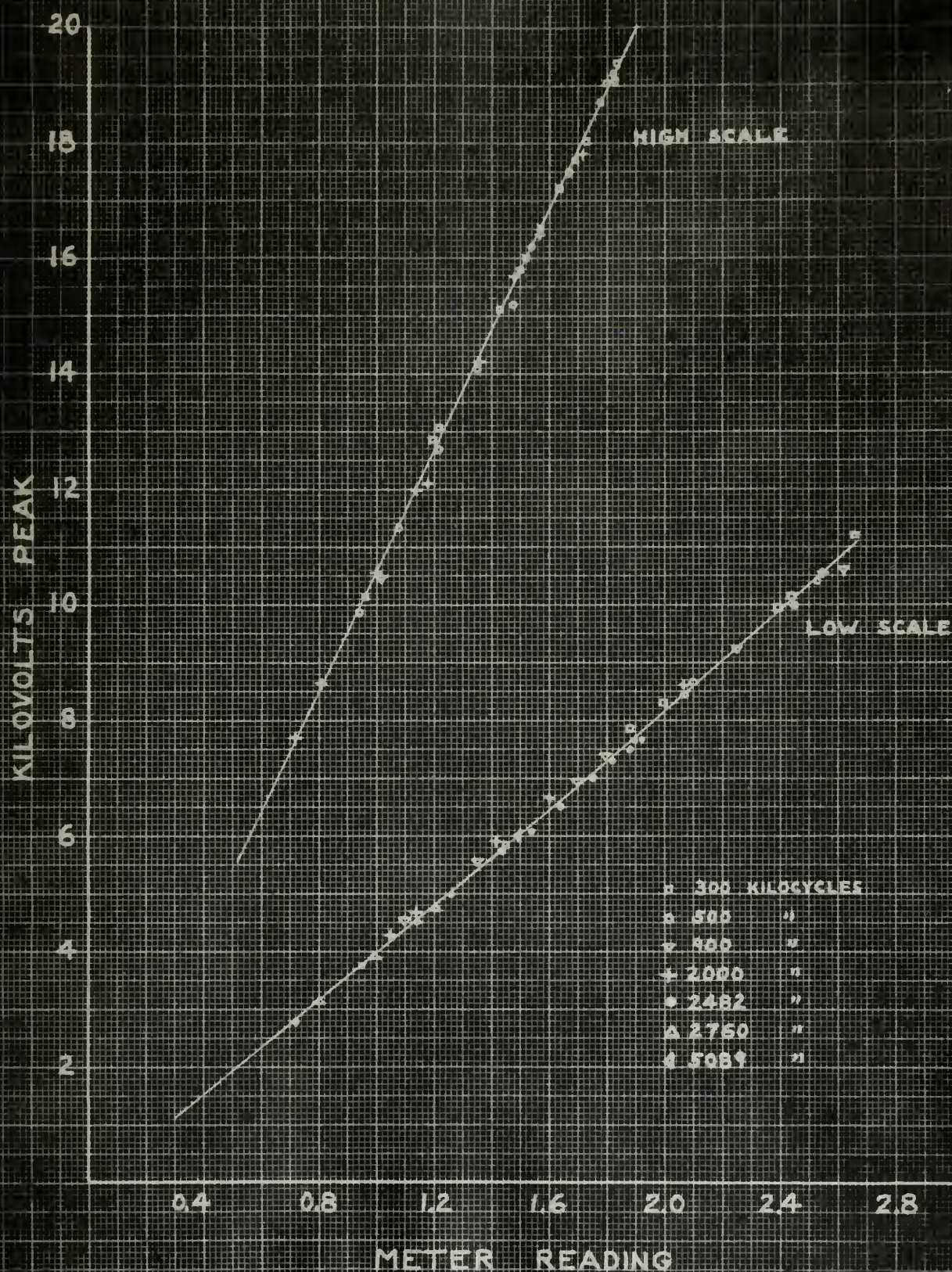
# DIRECT-CURRENT CALIBRATION OF THERMOCOUPLE







# VACUUM-TUBE VOLTMETER CALIBRATION







Its capacitance is about 2  $\mu\mu\text{F}$ . and its inductance of the order of 0.05 microhenry.

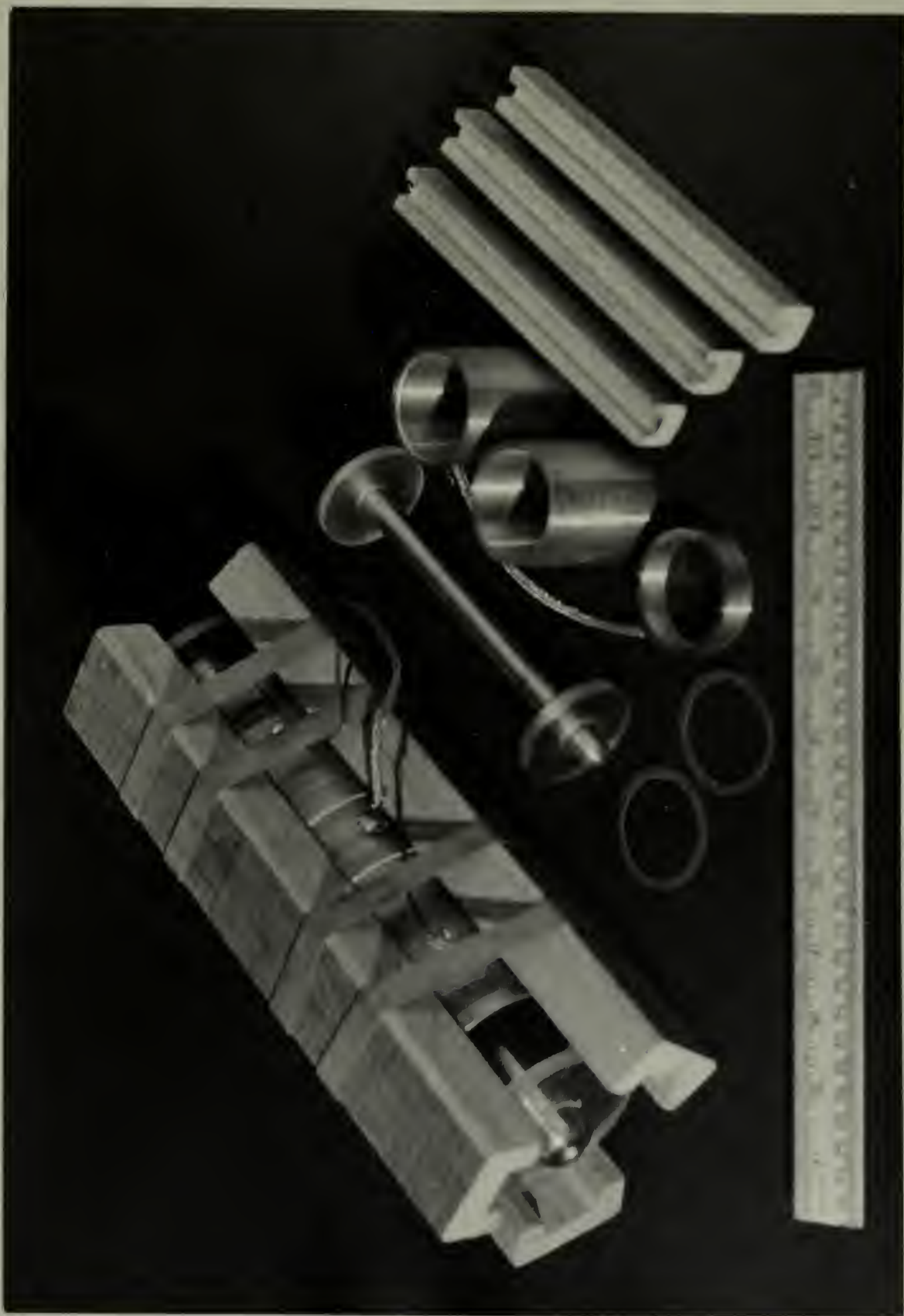
Two cylindrical capacitors were constructed. The second and larger one was built after the original one was found to be inadequate for voltages greater than 10 kilovolts peak. A photograph on page 16 shows these capacitors, and drawings of the larger one appear on page 17. For each capacitor, three interchangeable lengths of guarded outer cylinder were made, so that a wide range of voltage and frequency could be covered, while keeping the thermocouple current within its calibrated range. The resultant calibration of the capacitance-divider vacuum-tube voltmeter appears on page 14. The calibration is quite linear, and showed no variation with frequency in the range of frequencies, - 0.3 to 5 megacycles-over which it was calibrated.

Since the capacitor current read by means of the thermocouple is root-mean-square, while the voltmeter reads crest values, it was necessary to check the wave form during calibration. This was done by testing for harmonic content, using a General Radio Co. Precision Wavemeter type 724-A.

The thermocouple and cylindrical capacitor are not suitable for testing the sphere gaps directly, for several reasons. The first reason is that it is not a peak-reading arrangement, as is the vacuum-tube voltmeter. Secondly, the thermocouple current is proportional to frequency, so that the arrangement would have a different meter scale for each frequency. Thirdly, the meter scale is not linear,



The following table shows the results of the tests made on the various specimens of the material, and the values of the various properties. The values are given in the table in the form of percentages of the original values. The values are given in the table in the form of percentages of the original values. The values are given in the table in the form of percentages of the original values.



CYLINDRICAL CAPACITORS. THE SMALLER ONE IS SHOWN DISASSEMBLED.









whereas the vacuum-tube voltmeter is. And finally, the thermocouple has a considerable time lag.

#### Source of Test Voltage:

Two Navy-type radio transmitters served as the source of test voltages. One was rated 1000 watts C.W. from 300 kilocycles to 2000 kilocycles, and the other was rated 500 watts C.W. from 2 megacycles to 18 megacycles. These are master-oscillator, power-amplifier type transmitters. The high voltages were obtained by using a series-resonant circuit as load. A schematic diagram appears on page 19, and a photograph of the test set-up on page 20. Suitable coils were constructed, using No. 10 double-cotton-covered wire for the lower frequencies, and 1/4 inch copper tubing for the higher frequencies. The capacitances were simple discs of suitable sizes, set at variable distance above the ground plane. At the higher frequencies, the capacitance of the voltmeter plus the sphere gap or the cylindrical capacitor, was sufficient to achieve resonance.

#### The Sphere Gaps:

Two sphere gaps were used. The larger had brass spheres 6.25 cm. in diameter, and was made by General Electric Co. The smaller was constructed for this study, using brass spheres 2 cm. in diameter. Specifications of the American Standards Association<sup>(1)</sup> were followed. In addition, the support for the shank of the upper, ungrounded sphere was

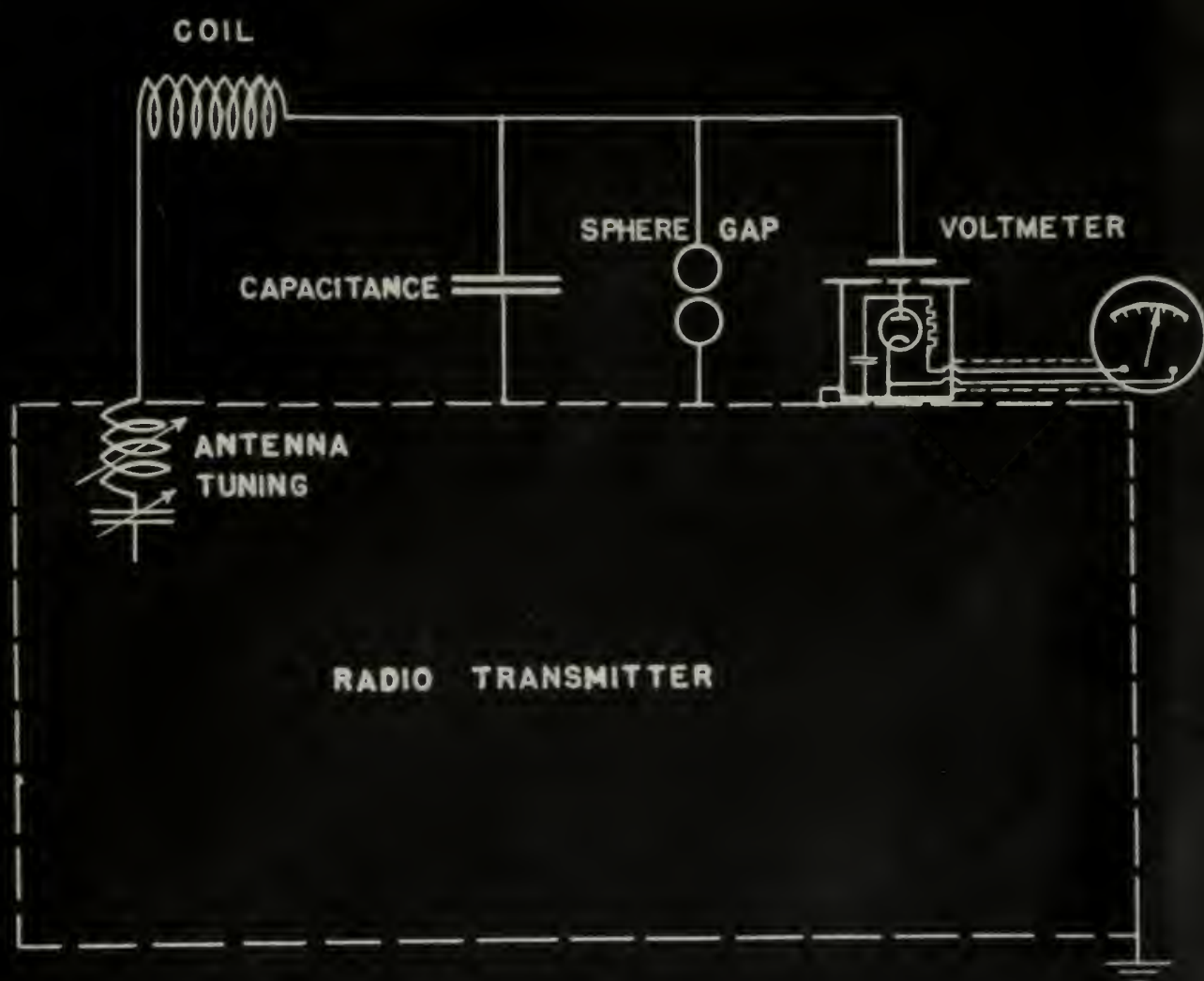
showing the various types of vegetation in the area, the  
character of the vegetation is as follows:

#### Types of Vegetation

The vegetation in the area is of the following types:  
of low vegetation, the area is covered with low  
vegetation in 2000 ft. areas, and the area is covered  
with 500 ft. areas, and the area is covered with  
medium-vegetation, medium-vegetation type vegetation. The  
high vegetation is covered with medium-vegetation type  
vegetation in 1000 ft. areas, and the area is covered  
with 500 ft. areas, and the area is covered with  
a photograph of the area is as follows: 1000 ft. areas  
are covered with 500 ft. areas, and the area is covered  
with 500 ft. areas, and the area is covered with  
for the lower vegetation, and 500 ft. areas are covered  
the higher vegetation. The vegetation is of the following  
at various places, and at various places above the ground  
area. At the higher places, the vegetation is of the  
vegetation type is as follows: 1000 ft. areas, and the  
are covered with 500 ft. areas.

#### The Forest Area

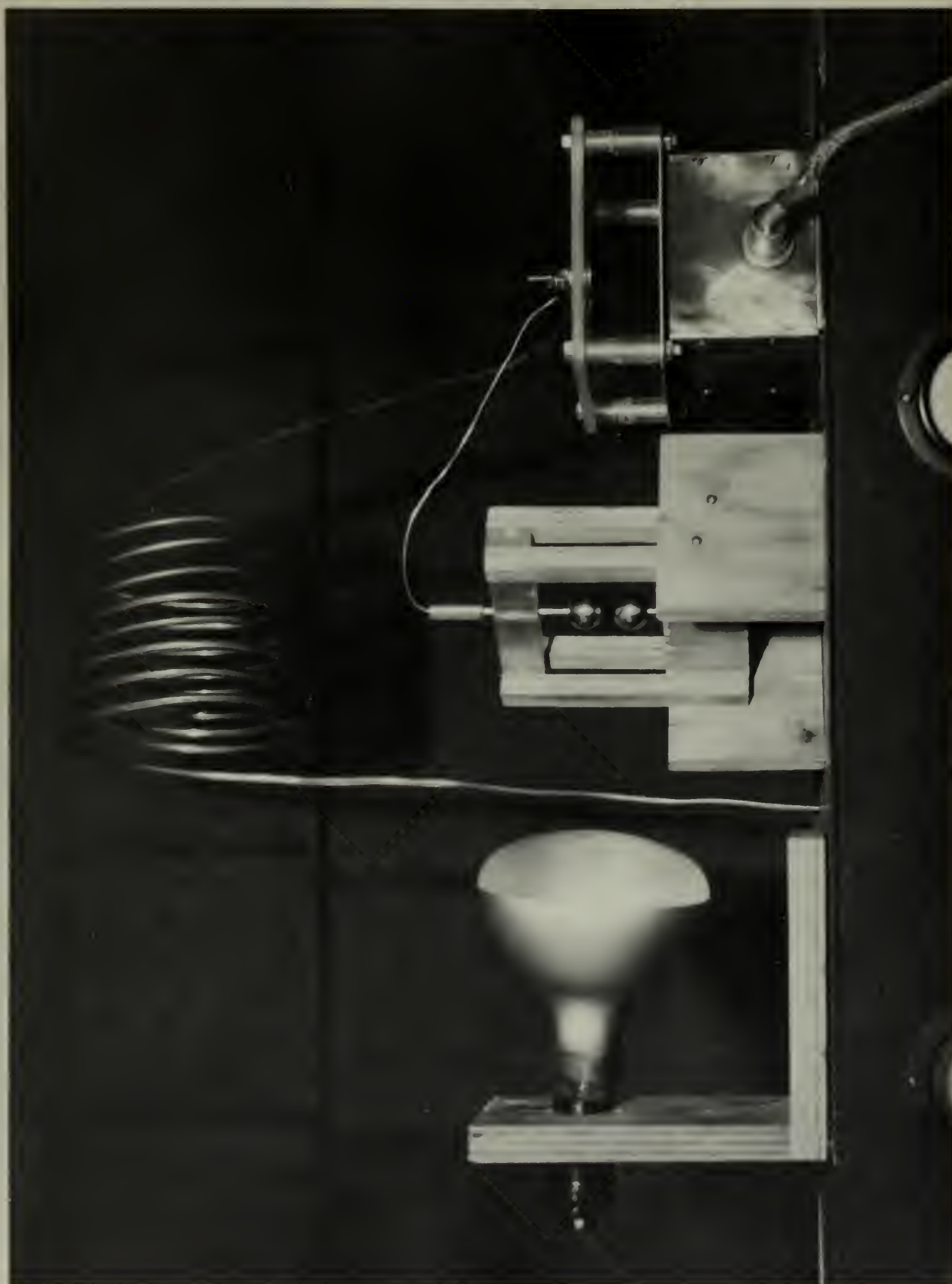
The forest area is as follows: The forest area is covered  
6.25 mi. in diameter, and the area is covered with 500 ft.  
The forest area is covered with 500 ft. areas, and the  
area is covered with 500 ft. areas. The forest area is  
covered with 500 ft. areas, and the area is covered with  
171  
forest area is covered with 500 ft. areas, and the area  
is covered with 500 ft. areas, and the area is covered  
with 500 ft. areas, and the area is covered with 500 ft.



SCHEMATIC DIAGRAM OF TEST SET-UP







THE TESTING SET-UP



made of polystyrene. In all tests the spheres were mounted in a vertical position, with the lower sphere grounded.

A rod gap also was constructed following specifications set forth by the American Standards Association<sup>(1)</sup>. Brass rods, 1/2 inch square and cut off squarely, form the two electrodes. Corners were not rounded off, but burr was removed.

#### Source of Irradiation:

A simple source of irradiation was chosen. This was a Westinghouse Co. type RS sunlamp, rated 110 volts, 275 watts, which fits into a standard lamp socket. It is a mercury-arc type, with a bulb of special glass which passes considerable ultra-violet light. It was found to be adequate for the purposes of this study.

#### Testing Procedure:

The following procedure was used to obtain the test data: A selected frequency was set up in the transmitter, and a suitable coil and capacitance arrangement was found which would provide a series-resonant load. The capacitance included the sphere gap and the voltmeter in parallel. Within the transmitter are an antenna loading coil and a coupling condenser which permitted a smooth final adjustment for resonance. The sphere gap was then set at a fixed gap value, determined by means of a feeler gauge, and the plate voltage on the final stage of the transmitter was increased until a preliminary spark-over occurred. Then with this voltage cut off,





the load was de-tuned slightly by means of either the antenna loading coil or the coupling capacitor, so that when plate voltage was re-applied to the output stage, the resultant voltage across the sphere gap was about 90% of spark-over value. This voltage was slowly increased by restoring the resonance through gradual manipulation of the antenna loading coil or coupling capacitor. The transmitter was cut off manually as soon as spark-over occurred, to avoid burning or pitting the spheres. Five such readings were taken. The ultra-violet light was then turned on and five more readings obtained with the spheres irradiated. Finally the sphere-gap setting was rechecked, before resetting to a new gap value.

Atmospheric pressure was read from a mercury-column barometer. Temperature and humidity were recorded from a wet and dry bulb thermometer.

Cleaning the spheres with crocus cloth, carbon tetrachloride, and soft cloth seemed to produce no effect on the results. Consequently, a great many spark-overs were recorded before stopping to clean the spheres.

#### EXPERIMENTAL RESULTS

The results of this study are presented in the form of curves, on pages 28 to 40. The original data are tabulated in Appendix B. For purposes of comparison, the spark-over

the fact that the only person who was not present at the time of the meeting was the person who was not present at the time of the meeting.



values for irradiated 2-cm spheres at 50 cycles<sup>(17)</sup>, together with the values found for irradiated spheres at the frequencies used in this investigation, are plotted on page 33. Wherever the scattering of the data is significant, the individual observations are plotted. Otherwise each point represents the average of five or more observations.

#### DISCUSSION OF RESULTS

The most noteworthy feature of the results is their consistency, particularly over such a wide range of frequencies. The consistency of individual observations, for a given gap setting and frequency, is also remarkable when the gap is irradiated. When the spheres are not irradiated, this consistency is not as good, and the readings are generally somewhat higher. This is in agreement with the results of other investigators. (4,7,13,14,15,16)

For very small gaps, if the frequency was not too high, the spark-over voltage seemed to coincide with that for power frequency. Then as the gap length was increased, there was a semi-abrupt transition to the lower spark-over values that are characteristic of the high frequencies. This effect is most clearly shown in the curves of spark-over voltages vs. frequency for fixed values of gap setting, page 38.

A possible theory to account for this is presented. A sinusoidal voltage having crest value slightly less than spark-over value, during its peak may form incipient breakdown streamers of ionized air part way across the gap.



When the investigation was begun at 10 o'clock, the  
with the same kind of investigation as the  
also went to this investigation and stayed on until 11.  
However the majority of the data is available, the  
differential investigation was placed. The data was  
summarized the nature of the in very brief.

### RESULTS OF INVESTIGATION

The most interesting feature of the results is their  
consistency, especially over such a wide range of frequency.  
The consistency of individual observations, the  
given for testing and frequency, is also remarkable and the  
gap is filled. When the above was not available, this  
consistency is not as good, and the results are generally  
summarized. This is in agreement with the results of  
other investigations. (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100)

For very small gaps, the frequency was not the same,  
the results were found to be similar to the results of the  
frequency. When the gap length was increased, there was  
a marked change in the frequency of the results. This effect is  
the characteristic of the gap frequency. This effect is  
most clearly shown in the case of very small gaps. It  
frequency for these gaps of gap length, and it  
a possible theory is shown for this is presented.  
The results of the investigation are given in the following  
figures, showing the results of the investigation. The  
and the results of the investigation are given in the following

During the remainder of the half-cycle, these ions will be attracted toward the sphere surfaces, and if the cycle is not too brief, or the distance to be travelled not too long, effective de-ionization of the gap will take place before the next voltage peak occurs.\* At power frequency, this takes place for any gap of reasonable length. And if this theory is correct, the experimental results of this study indicate that this de-ionization takes place for example, at 300 kilocycles for a gap length of 1 millimeter, but does not take place if the gap is 2 millimeters. From this, a rough calculation gives a figure for ion mobility of about 3 cm/sec/volt/cm. (See Appendix A). This is in good agreement with the value 3 - 4 cm/sec/volt/cm derived recently by another investigator<sup>(19)</sup> from probe measurements of 60-cycle corona.

Another feature of the curves of spark-over voltage vs. frequency, for various fixed gap lengths, page 38, is the appearance of definite minima. These minima are functions of gap length and frequency, as is most clearly shown by the curve on page 39, where the reciprocal of the frequency at which the minimum occurs for a fixed gap length, is plotted against gap length. The nearly linear form of this curve suggests that the product  $gf_m$  is relatively constant, where  $g$  is gap length and  $f_m$  is the frequency at which the minimum occurs. The product  $gf_m$ , over the range of gaps from 0.77 millimeters to 6 millimeters, is found to be  $(4 \pm 0.5) \times 10^5$ ,

-----  
\*This theory is essentially the same as that proposed by Pim<sup>(20)</sup>, who studied gaps of less than 1 millimeter, at frequencies from 100 to 300 megacycles.

[illegible]



where  $f_m$  is in cycles per second, and  $g$  is in centimeters.

To account for these minima, the possibility of ionic oscillations was considered. Such oscillations, at frequencies of the same order of magnitude as these minima, (about 1 megacycle) have been reported in the study of the plasma of low-pressure gaseous discharges<sup>(26)</sup>. Their velocity of propagation  $v$  can be calculated theoretically from  $v = \left(\frac{kT}{M}\right)^{1/2}$ , where  $k$  is the Boltzmann constant,  $T$  is the electron temperature, and  $M$  is the mass of an ion. (For nitrogen,  $M = 23.27 \times 10^{-24}$  grams). Assuming  $T$  to be about 30,000 degrees absolute, gives a velocity of propagation  $v = 4.2 \times 10^5$  centimeters per second. Now on page 38, the curve for a 6-millimeter gap shows a minimum at about 550 kilocycles (point A). Assuming an ionic oscillation to exist, and its wavelength to be twice the gap length, a velocity of propagation of  $6.6 \times 10^5$  centimeters per second is calculated. This is in fair agreement with that calculated from the theory.

A resonance between the frequency of applied field and ionic oscillations could serve to lower the breakdown voltage of the gap, because at resonance the ionic oscillations would be enhanced, and additional energy would be supplied to the gap by the applied voltage. An increase of ionization, and lowered break-down strength would logically result.

In the curves, page 38, there is also some evidence of a second set of minima to be expected at much higher frequencies than those used in this investigation. These could be associated with a resonance effect involving electronic



[illegible]

oscillations. The ratio of the mass of a nitrogen ion to that of an electron is about 26000 to 1. Assuming the resonant frequency to vary inversely as the square root of the mass, a second minimum might therefore be expected at a frequency 160 times that which has been ascribed to ionic oscillations. The conjectured appearance of such a minimum at about  $10^8$  cycles per second (point B), has been sketched in a dotted extrapolation of the curve on page 38, for the case of a gap length of 6 millimeters. Electronic oscillations having frequencies of this order of magnitude have been found in studies of the plasma of gaseous discharges<sup>(26)</sup>.

The sphere-gap results are in general agreement with previous studies, particularly those of Ekstrand<sup>(6)</sup>, who made tests with 2-cm. irradiated spheres at 700 kilocycles and 1800 kilocycles. Seward<sup>(4)</sup> and Alford and Pickles<sup>(5)</sup> report values about 15% higher, and Reukema<sup>(5)</sup> values about 5% lower than those of this investigation, for corresponding frequencies. These differences may be due to the lack of irradiation, and to the use of a different intensity of irradiation, respectively, because apparently spark-over value does decrease somewhat with increased intensity of irradiation. (13,14,15,16) During this investigation, the ultra-violet light was maintained at a distance of 10 cm. from the gap, for the sake of uniformity. However, moving the lamp closer seemed to produce no measurable difference in the spark-over values.

oscillations. The angle of the wave at a distance less than  
 that of the distance is about 2000 to 1. Assuming the  
 constant frequency is not inversely as the square root of  
 the mass, a small change in the frequency is expected at  
 a frequency 100 times that which has been assumed to form  
 oscillations. The calculated frequencies of such a system  
 at first 10<sup>10</sup> times the mass (about 10<sup>10</sup>), has been assumed  
 in a direct proportion of the mass to give 10<sup>10</sup> for the  
 case of a new length of a millimeter. Elastic oscillations  
 show better frequency of this order of magnitude than  
 have been in relation to the mass of masses (about 10<sup>10</sup>).  
 The constant mass is in general agreement with  
 previous studies, particularly those of (A), and made  
 based on 2-sec. intervals shown as 700 milliseconds and  
 1000 milliseconds, (A) and (B) and (C) (B) (C) (D) (E)  
 (F) (G) (H) (I) (J) (K) (L) (M) (N) (O) (P) (Q) (R) (S) (T) (U) (V) (W) (X) (Y) (Z)  
 (AA) (AB) (AC) (AD) (AE) (AF) (AG) (AH) (AI) (AJ) (AK) (AL) (AM) (AN) (AO) (AP) (AQ) (AR) (AS) (AT) (AU) (AV) (AW) (AX) (AY) (AZ)  
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 (FA) (FB) (FC) (FD) (FE) (FF) (FG) (FH) (FI) (FJ) (FK) (FL) (FM) (FN) (FO) (FP) (FQ) (FR) (FS) (FT) (FU) (FV) (FW) (FX) (FY) (FZ)  
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 (XA) (XB) (XC) (XD) (XE) (XF) (XG) (XH) (XI) (XJ) (XK) (XL) (XM) (XN) (XO) (XP) (XQ) (XR) (XS) (XT) (XU) (XV) (XW) (XX) (XY) (XZ)  
 (YA) (YB) (YC) (YD) (YE) (YF) (YG) (YH) (YI) (YJ) (YK) (YL) (YM) (YN) (YO) (YP) (YQ) (YR) (YS) (YT) (YU) (YV) (YW) (YX) (YY) (YZ)  
 (ZA) (ZB) (ZC) (ZD) (ZE) (ZF) (ZG) (ZH) (ZI) (ZJ) (ZK) (ZL) (ZM) (ZN) (ZO) (ZP) (ZQ) (ZR) (ZS) (ZT) (ZU) (ZV) (ZW) (ZX) (ZY) (ZZ)



The rod gap was investigated, because it appears in the American Standards Association publication<sup>(1)</sup>. Its use at these high frequencies does not seem to offer a great promise. For very small gap settings the results tend to be erratic, while for gaps much over 2 cm., corresponding to about 14 kilovolts peak, there was an unpredictable tendency for a flamelike discharge to strike from any one of the sharp corners of the upper electrode. This discharge would not strike to the lower, grounded electrode, but would extend out into space, more or less like corona. About the only feature in favor of the rod gap is its ease of construction.

On page 40 there is presented in graphical form a survey of published test results on the dielectric strength of air, covering a broad range of frequencies. The results of this report are included, for comparison. The various investigations were conducted under widely different conditions, so that not all are subject to direct comparison. In compiling this survey, the values corresponding to irradiated spheres with a gap spacing of 0.5 cm. were chosen wherever possible.\* This survey indicates that over a wide spectrum of frequencies, the dielectric strength of air does not vary a great deal.

-----  
\* In computing the dielectric strength of air at high frequencies, from the spark-over voltages of the various sphere gaps, the correction factor set forth by Peek, (2, page 28) was not used, because the results of this report, and a study of the available published data, indicate that this correction factor does not apply at high frequencies, for the sphere sizes and gap lengths considered.

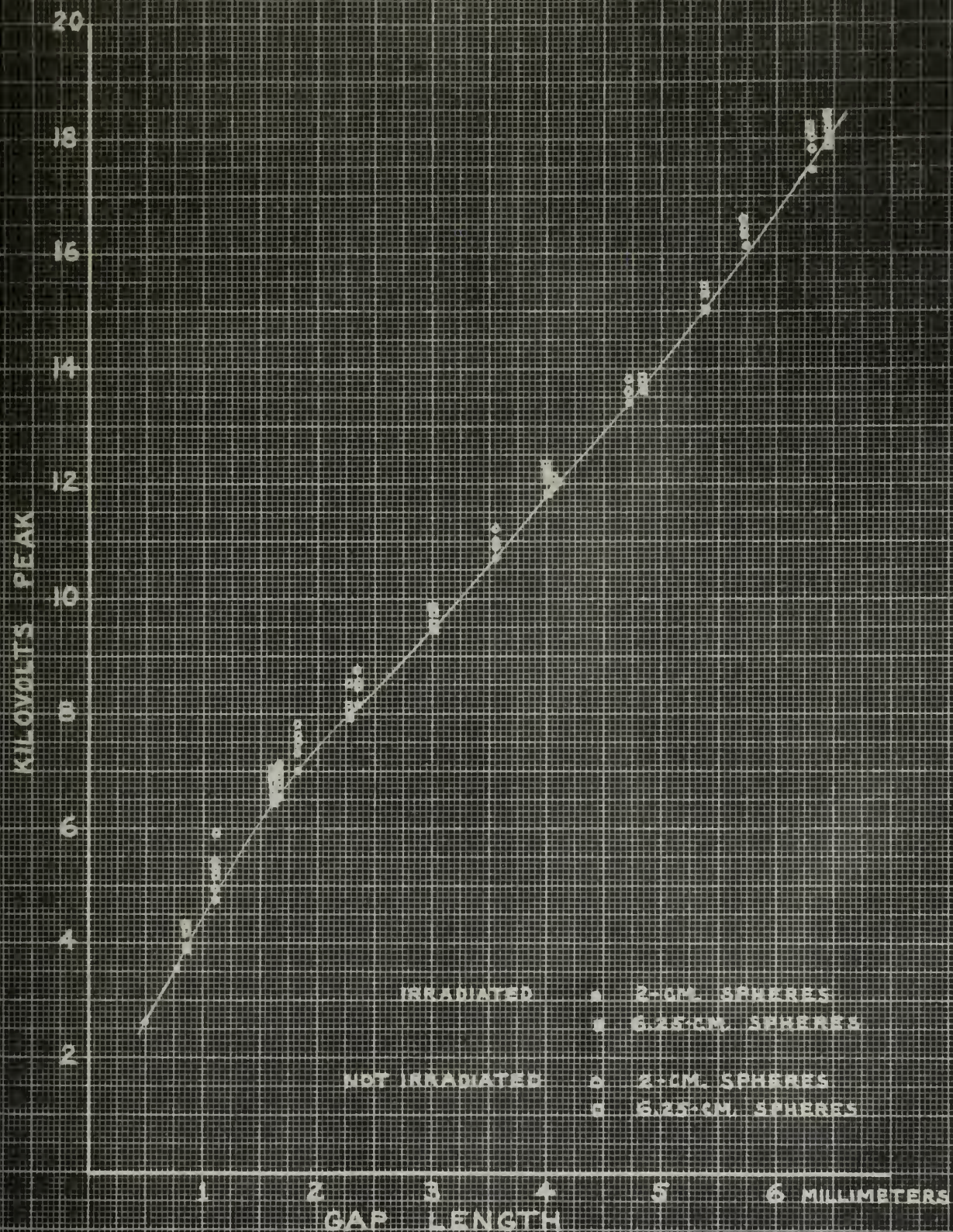


that not all are subject to direct sunlight. In weighing this matter, the extent of exposure to direct sunlight, with a sun shining at 60° or more above horizon position, this sunny influence has been a factor of 1000-1500. The average strength of the sun has been about 1000.

It is possible that the information contained in this report, from the confidential source of the source, may be of value to the source of the source, and a copy of the report may be of value to the source of the source. It is possible that the information contained in this report, from the confidential source of the source, may be of value to the source of the source, and a copy of the report may be of value to the source of the source.



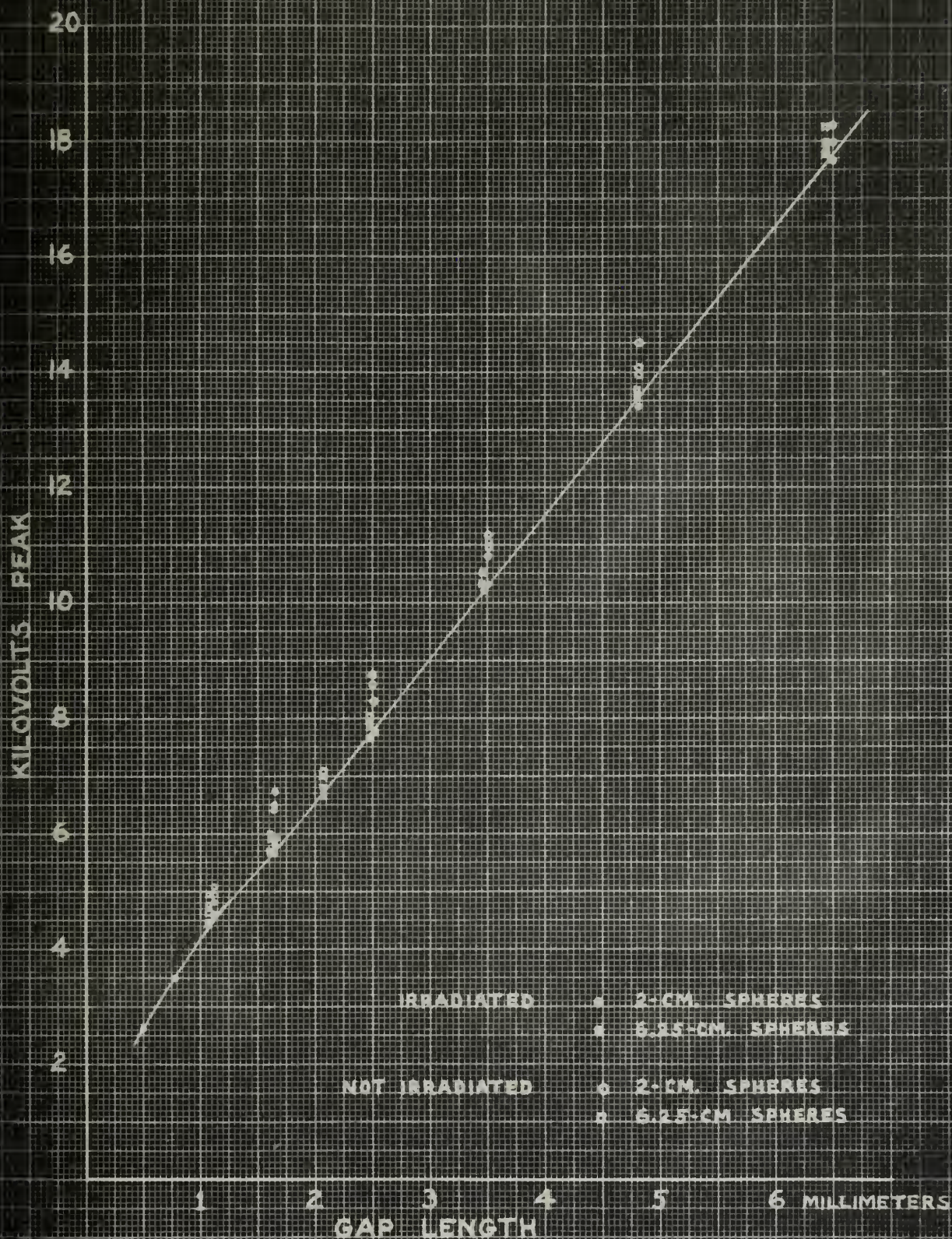
# SPHERE GAPS AT 308 KILOCYCLES



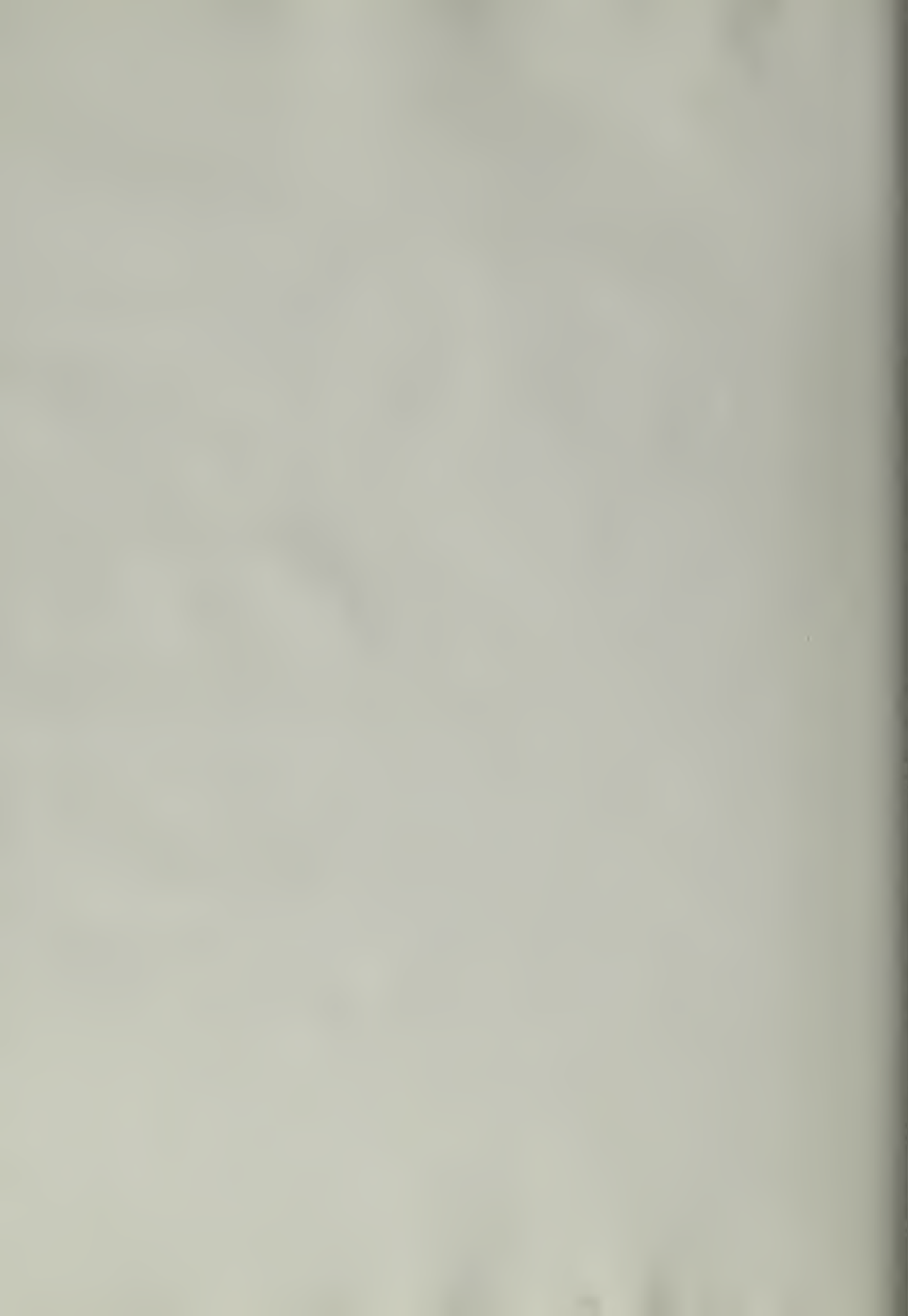




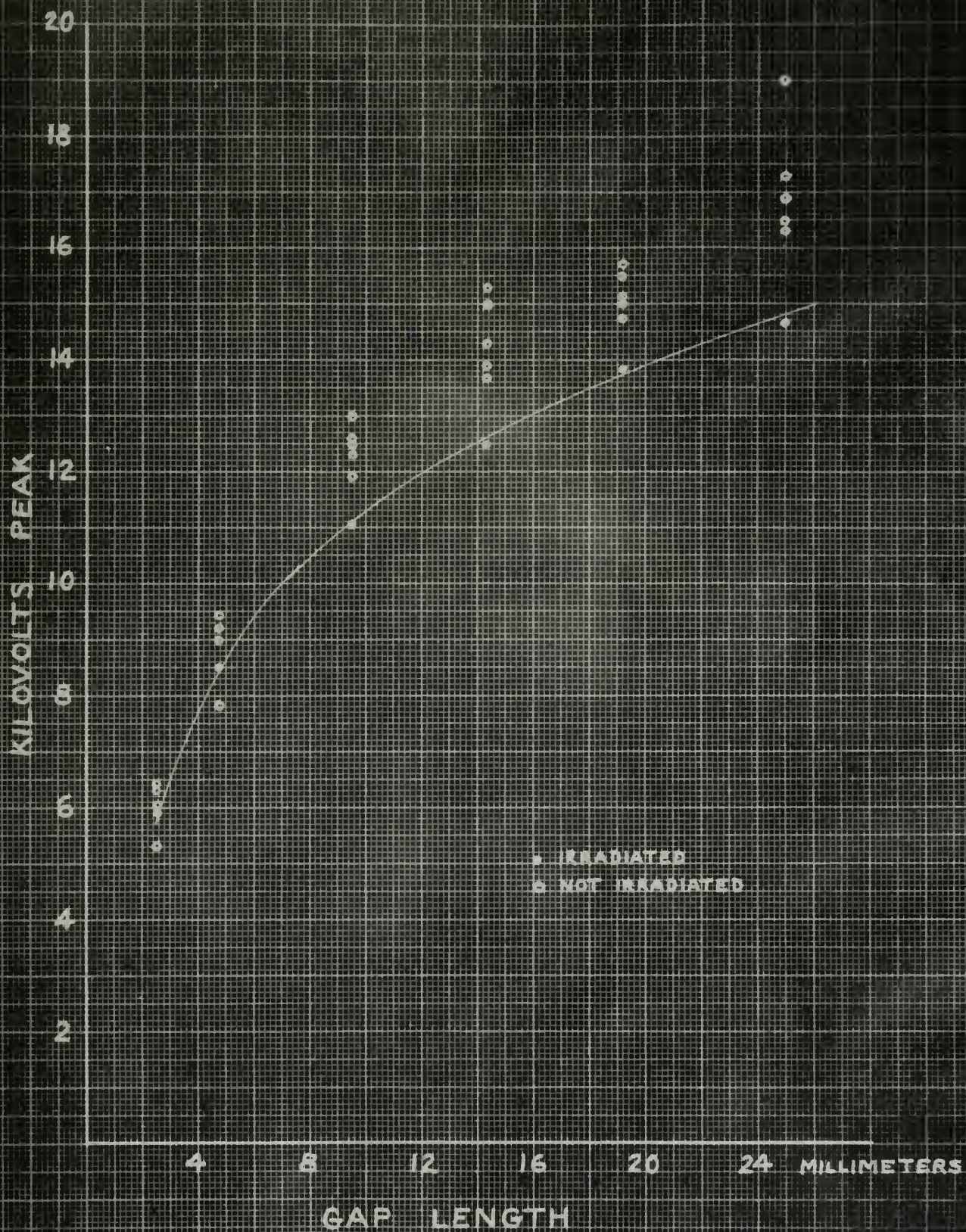
# SPHERE GAPS AT 750 KILOCYCLES



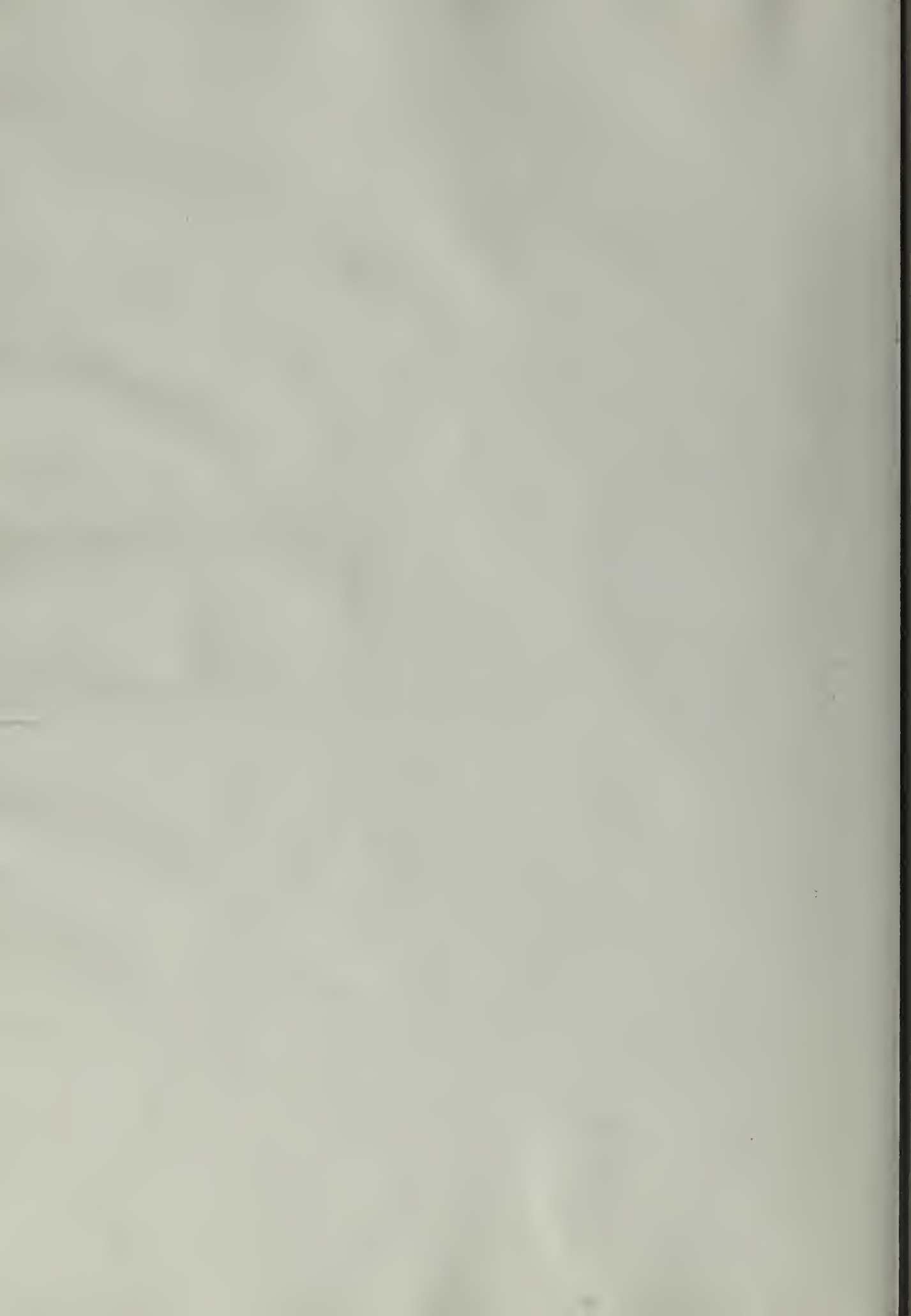




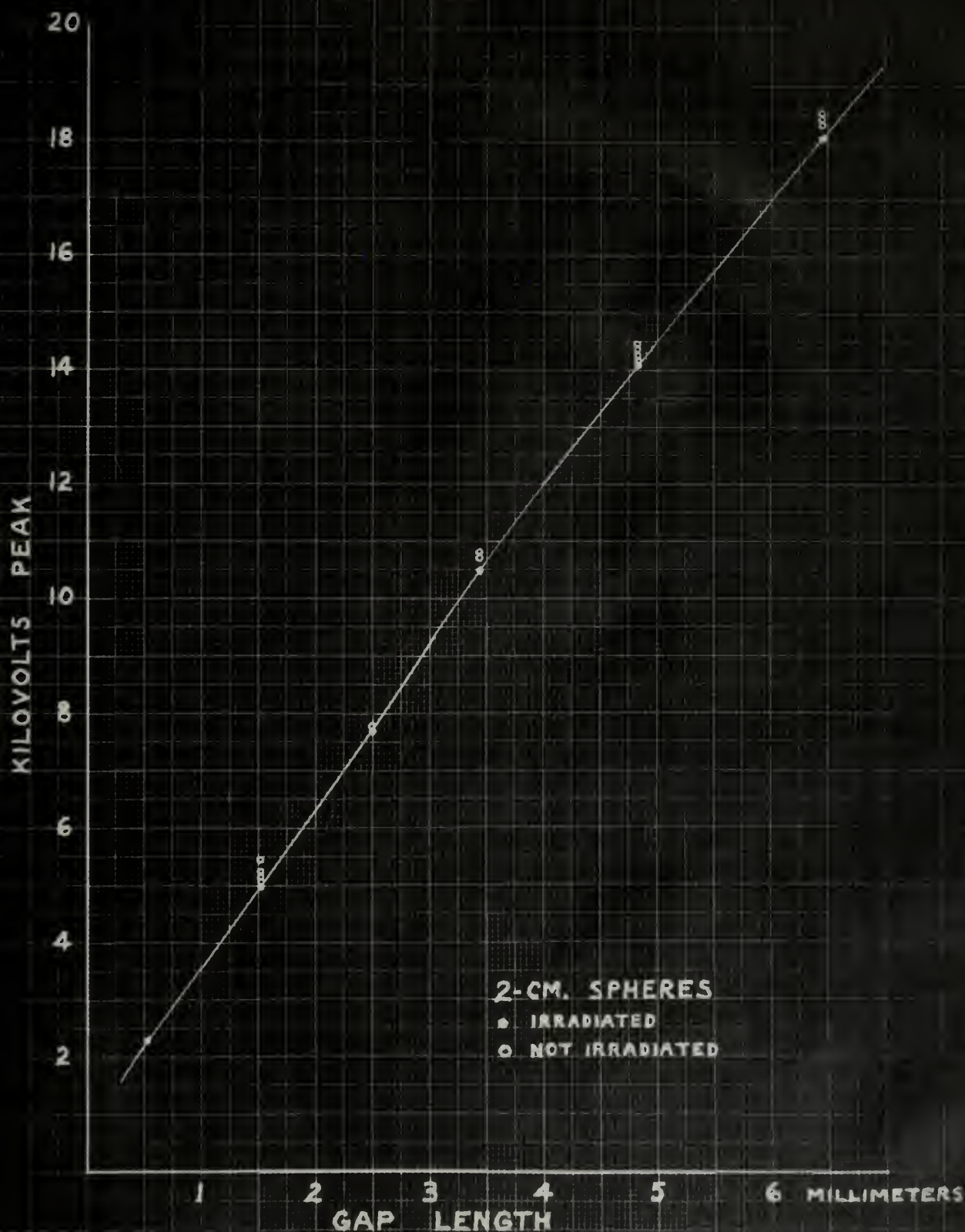
# ROD GAP AT 2088 KILOCYCLES



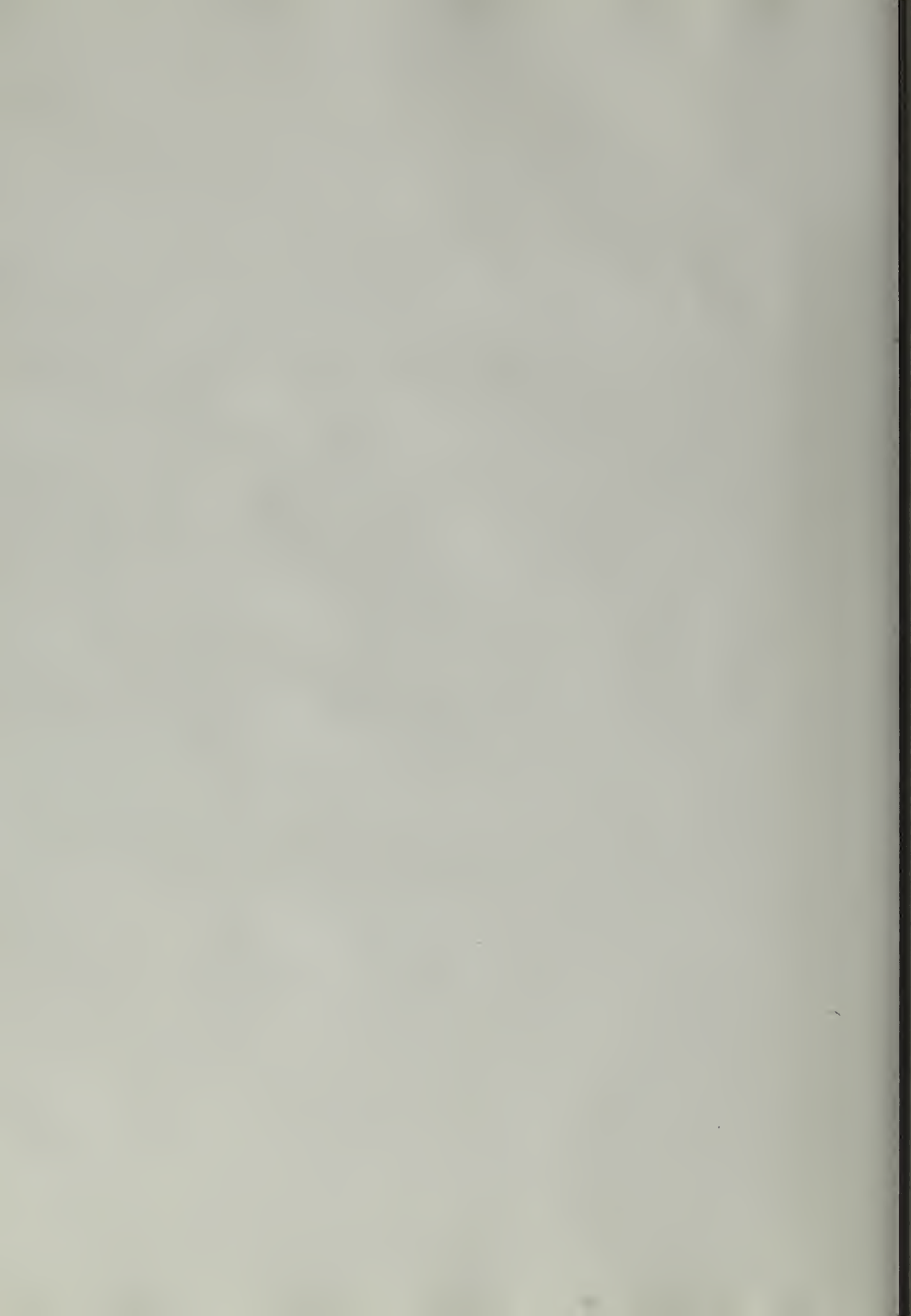




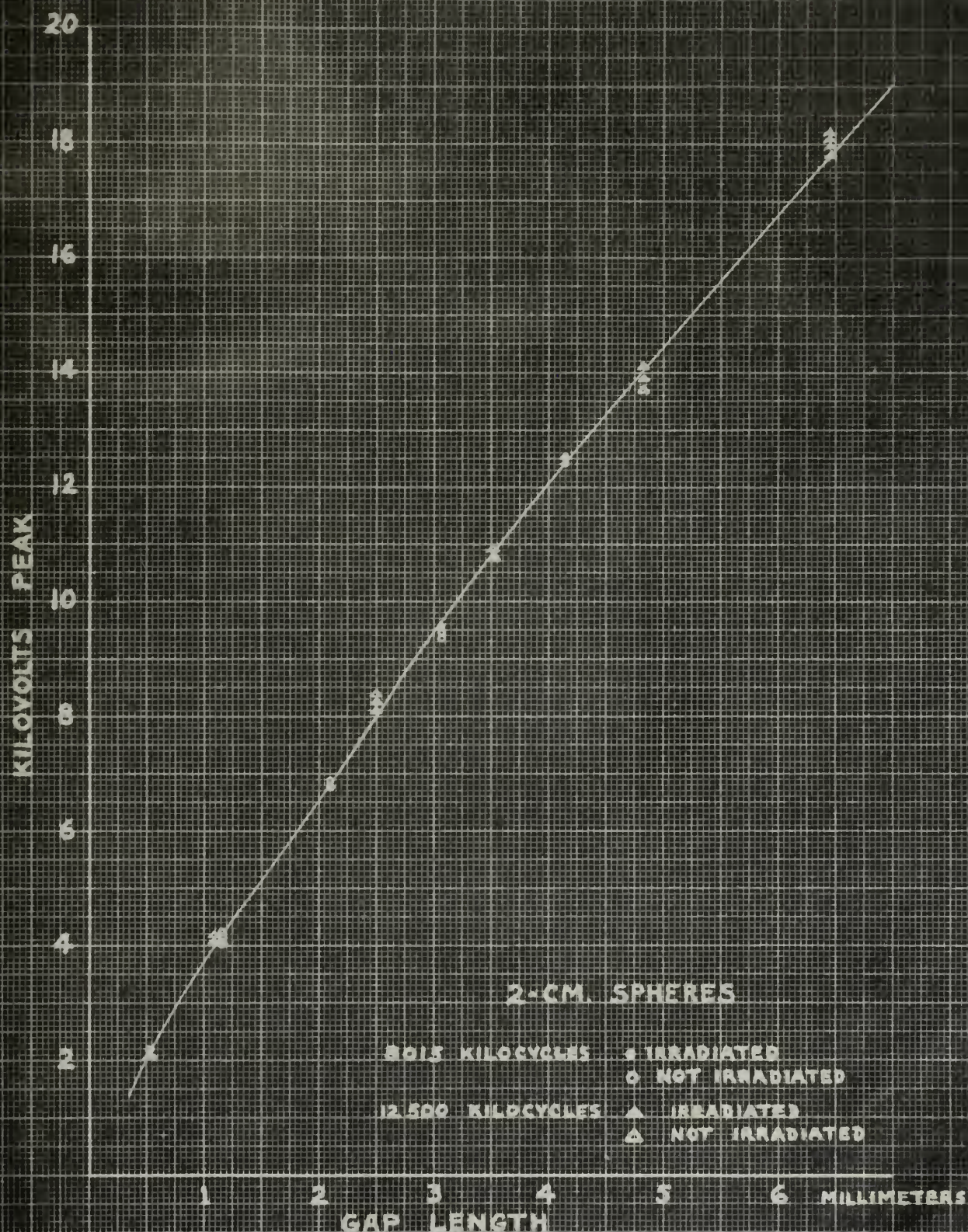
# SPHERE GAPS AT 4873 KILOCYCLES



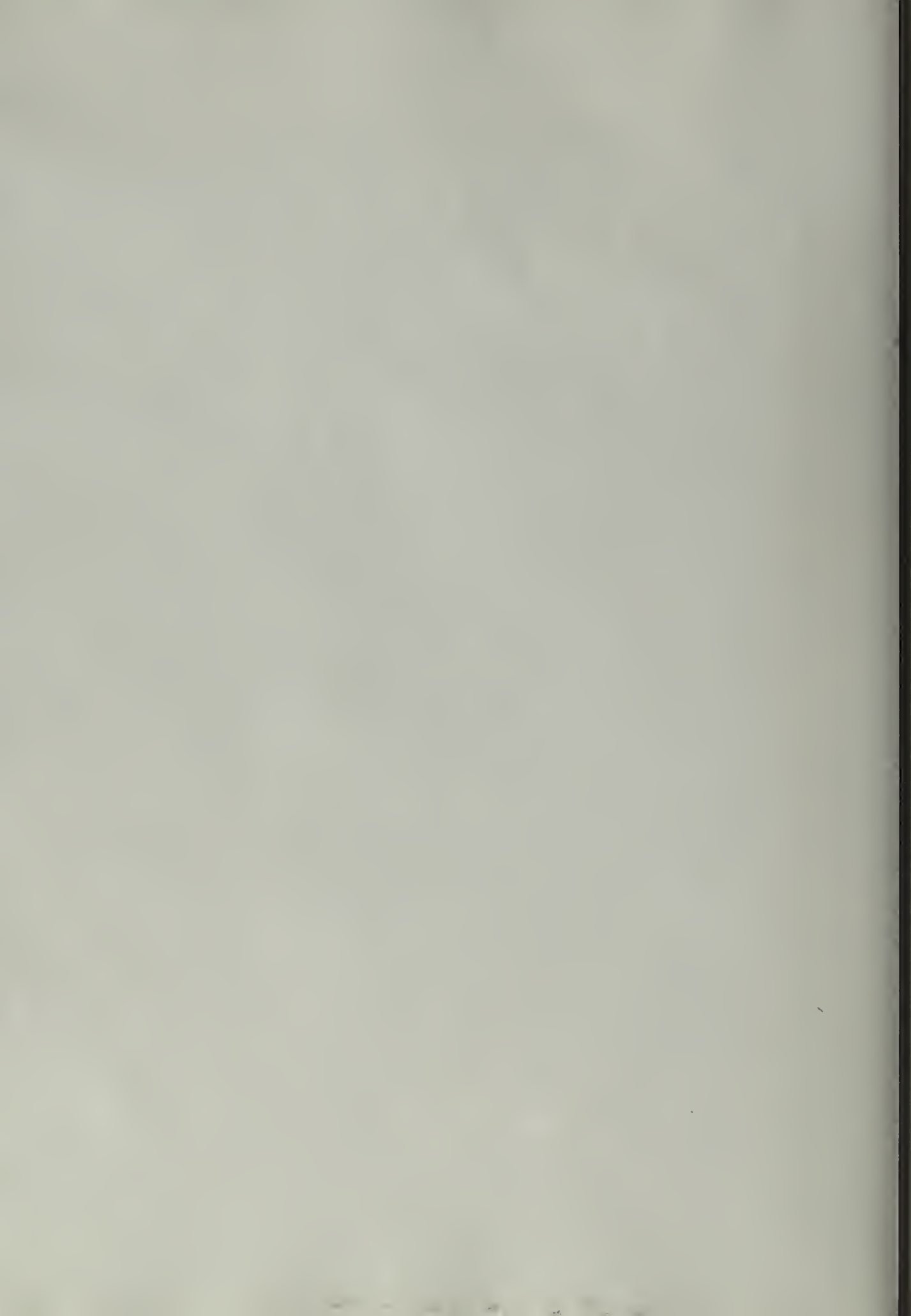




# SPHERE GAPS AT 8015 KILOCYCLES AND 12 500 KILOCYCLES



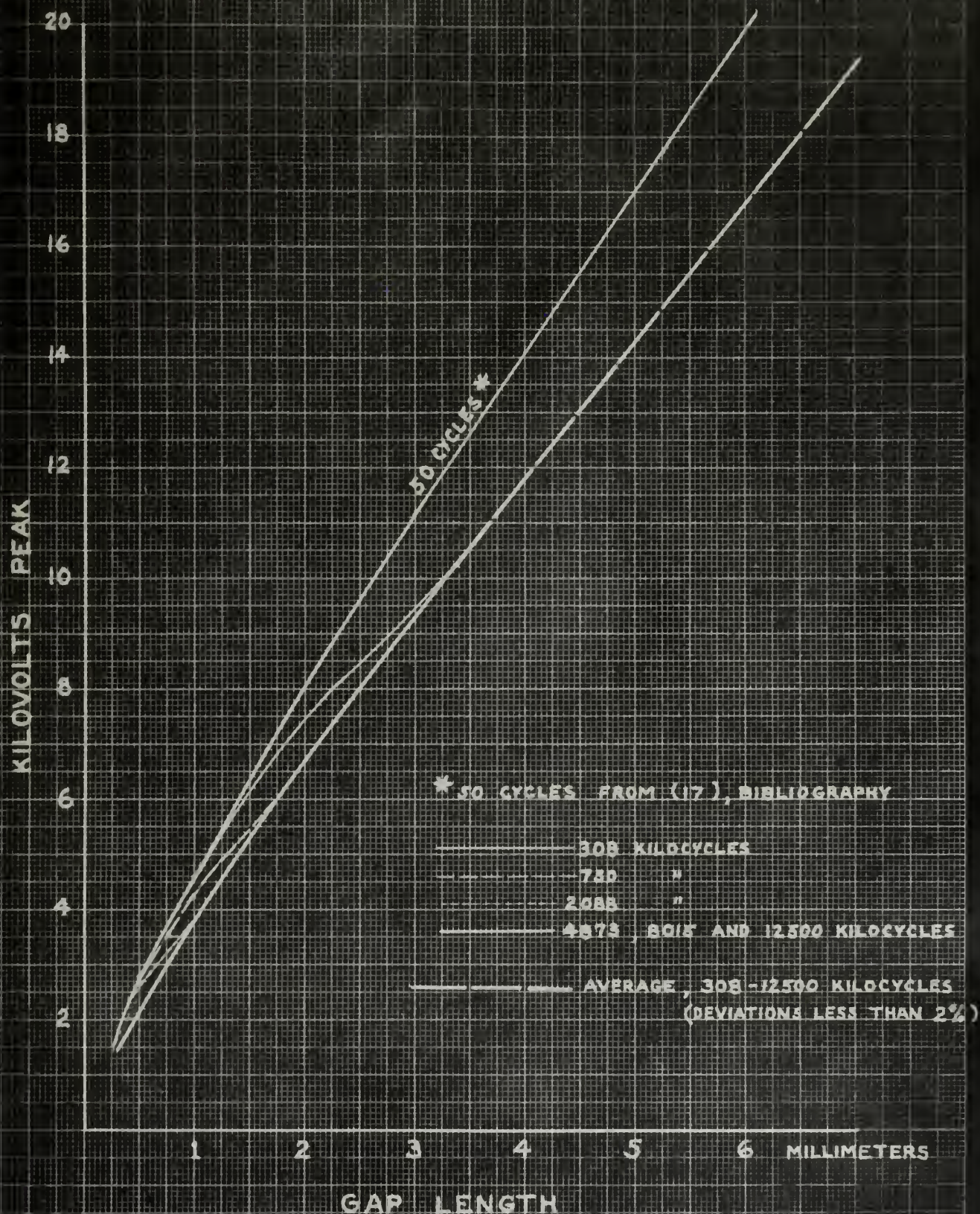


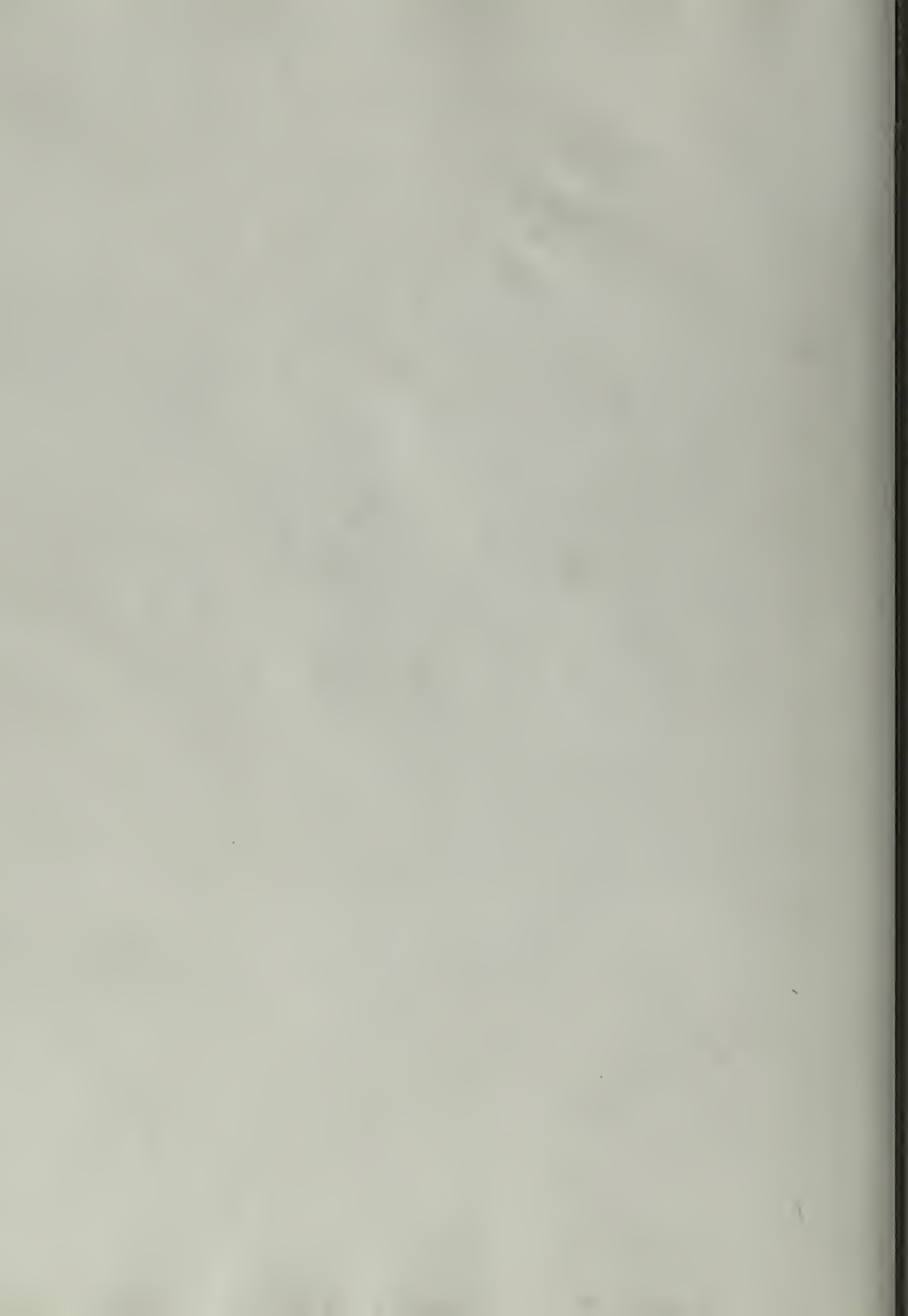




# SUMMARY OF SPHERE GAP TESTS

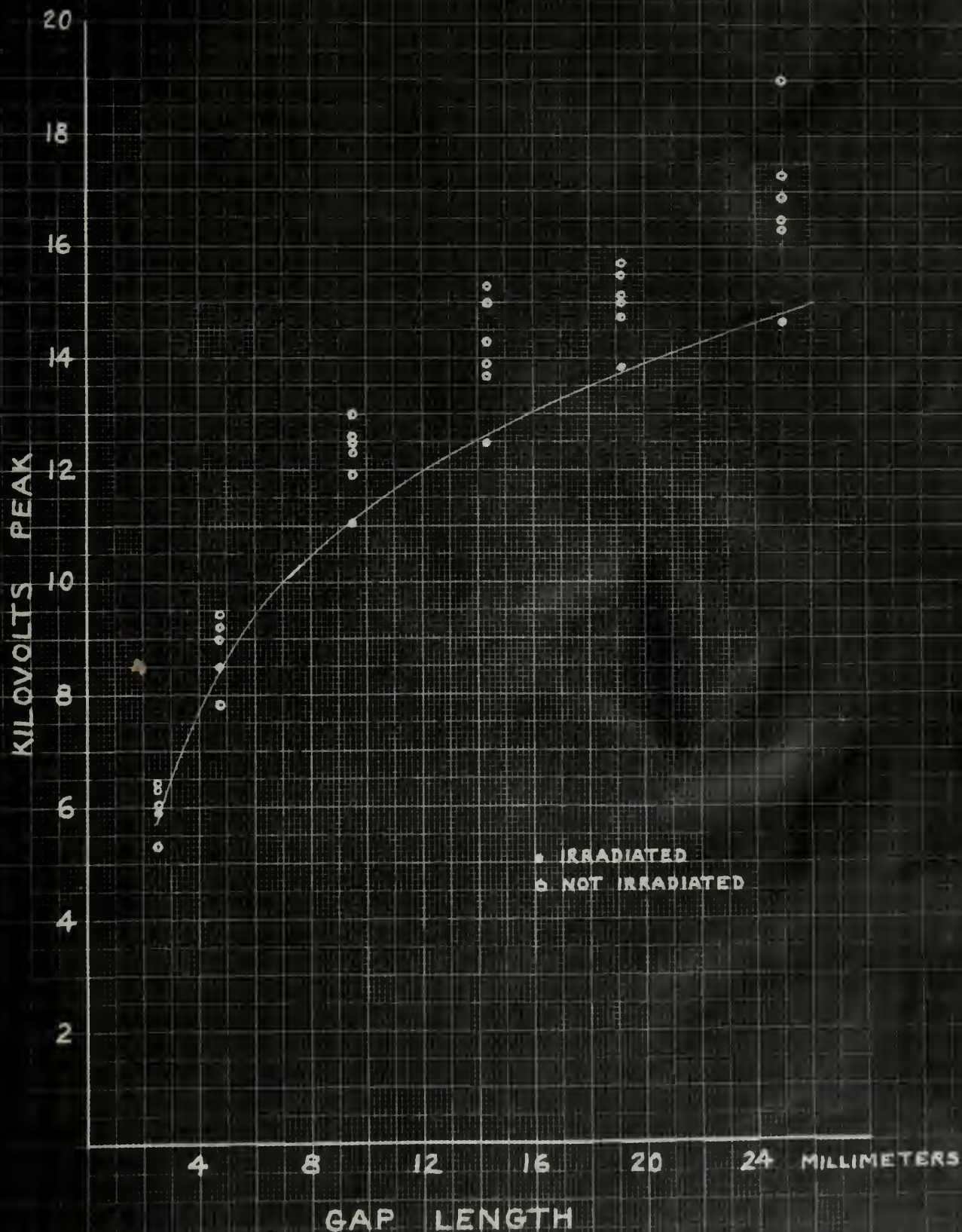
2-CM. SPHERES, IRRADIATED



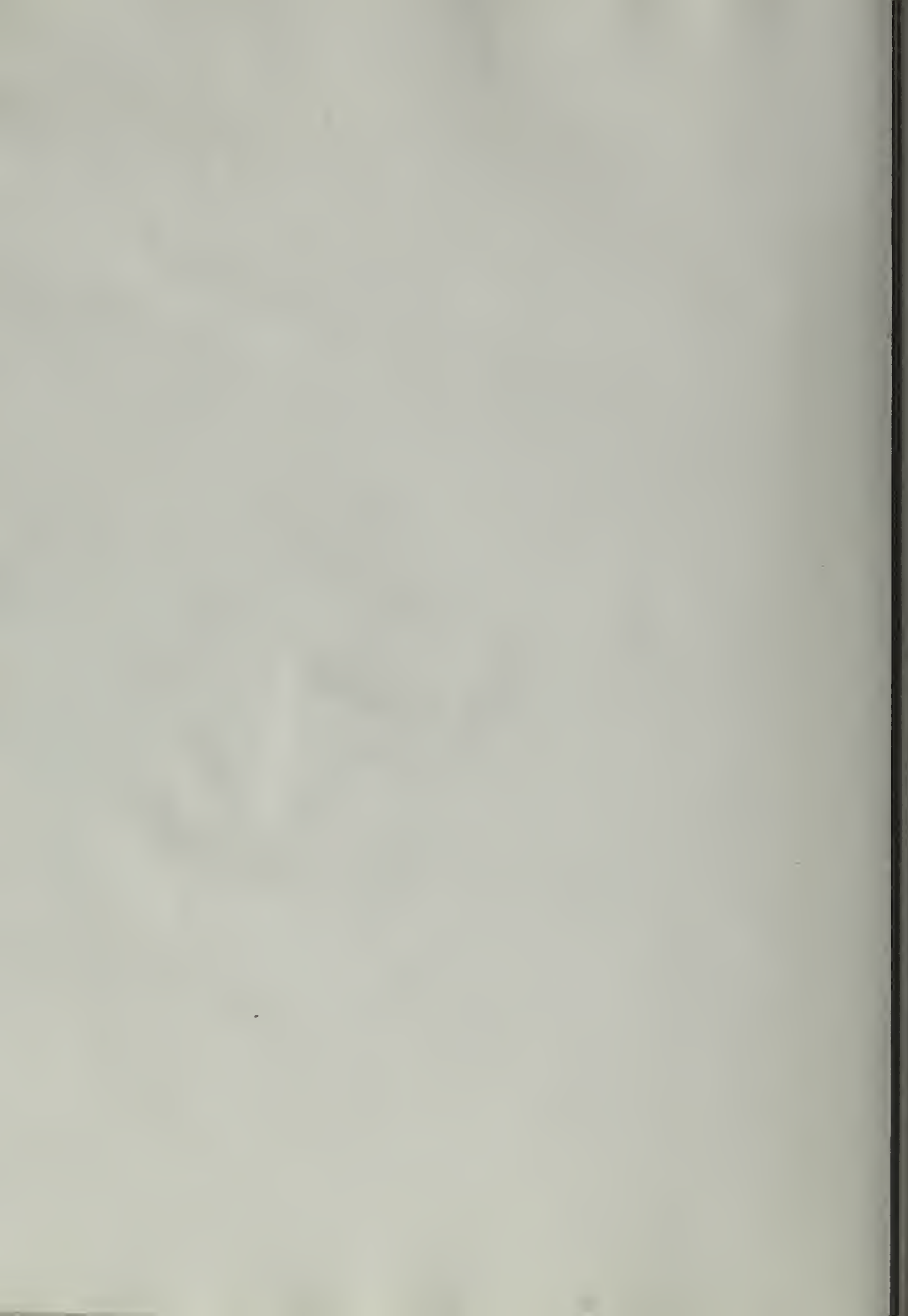




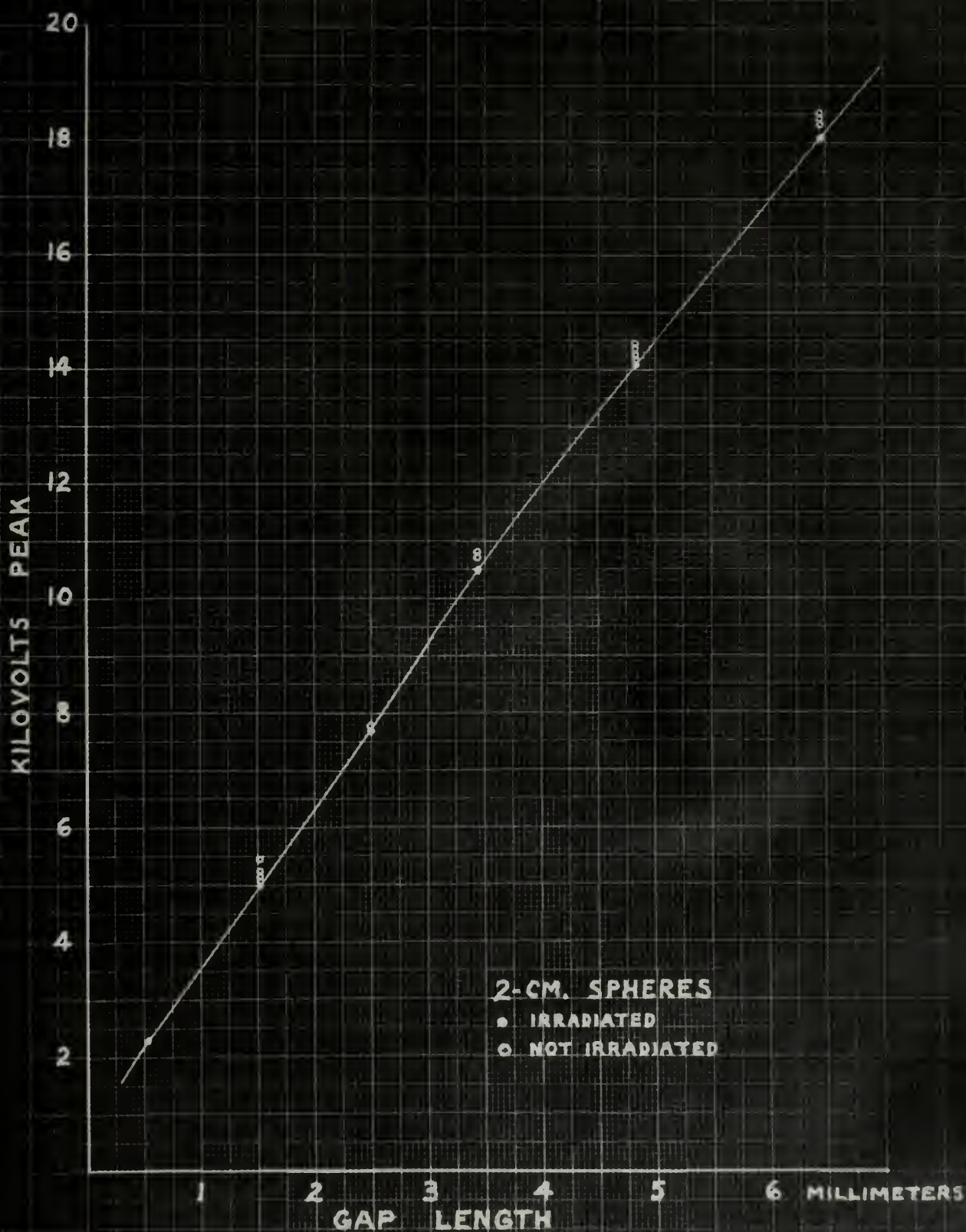
# ROD GAP AT 2088 KILOCYCLES

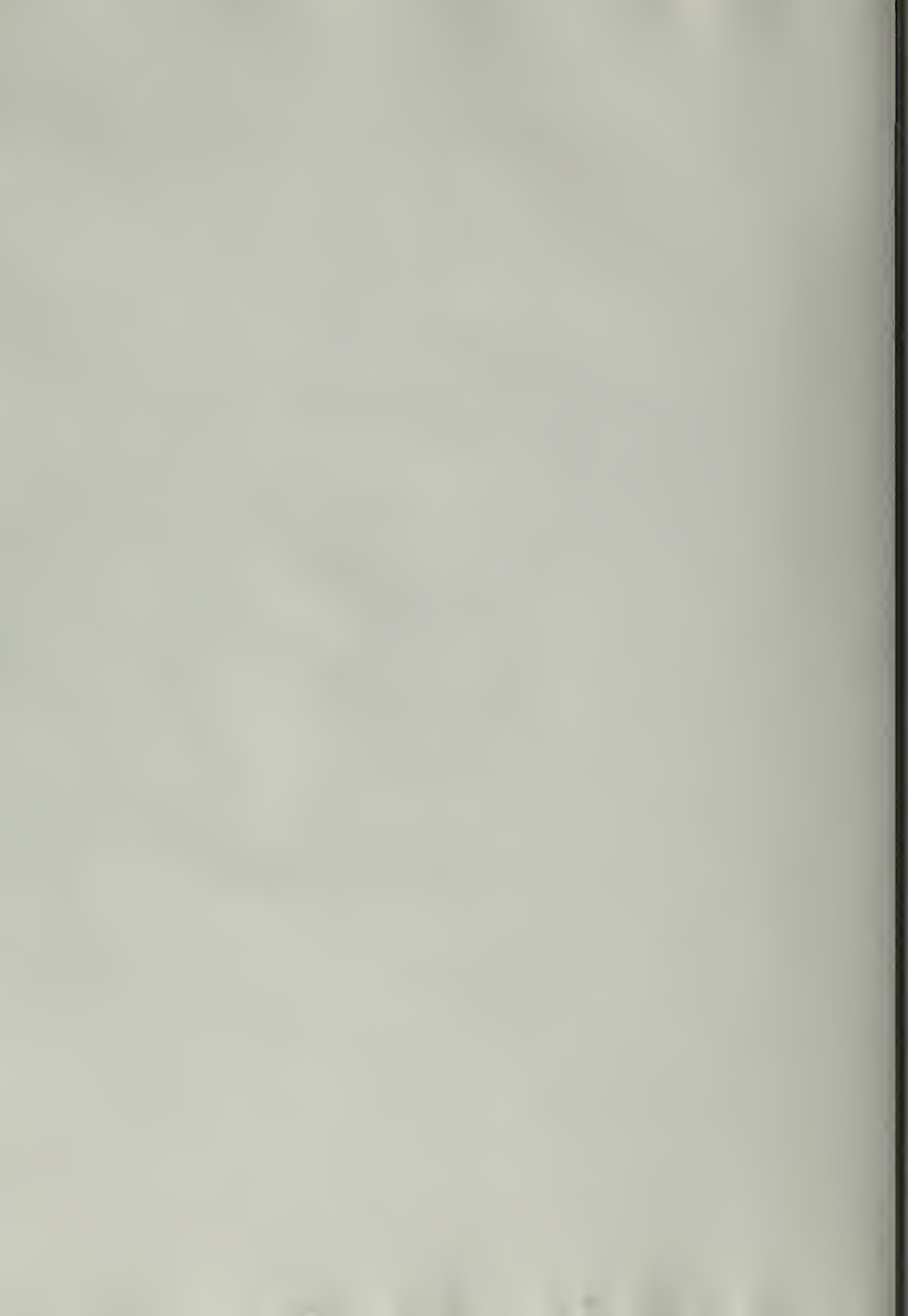






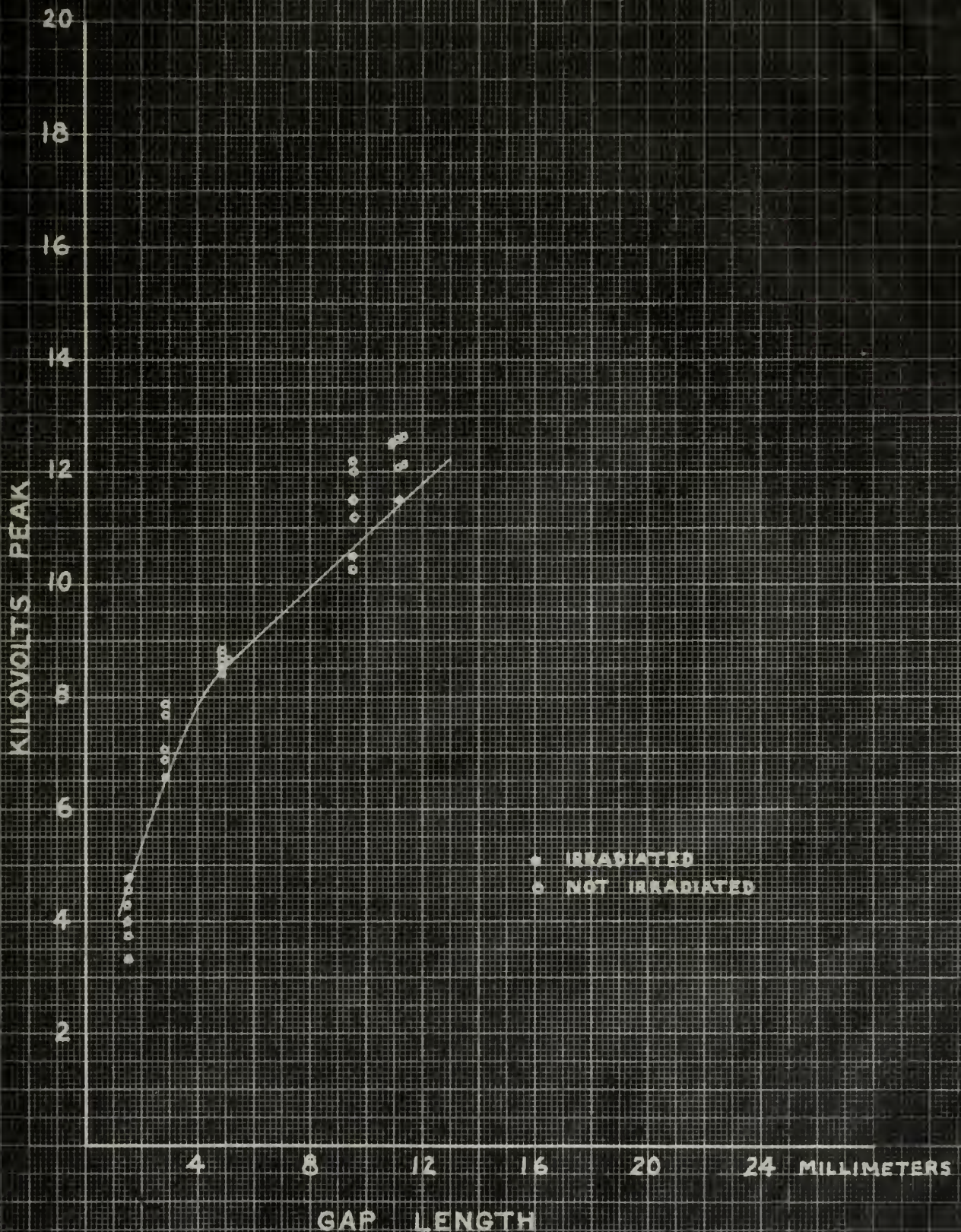
# SPHERE GAPS AT 4873 KILOCYCLES







# ROD GAP AT 8015 KILOCYCLES

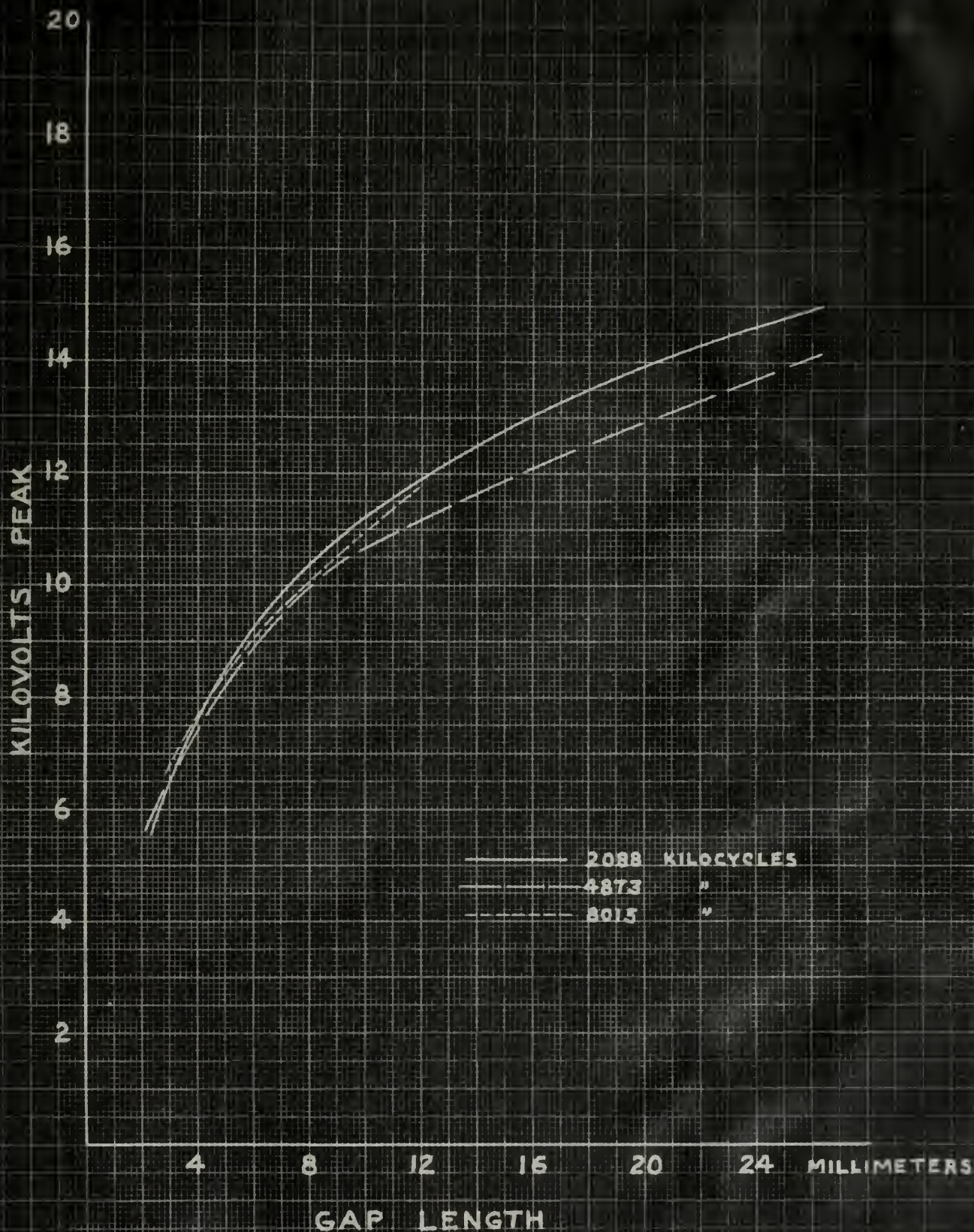




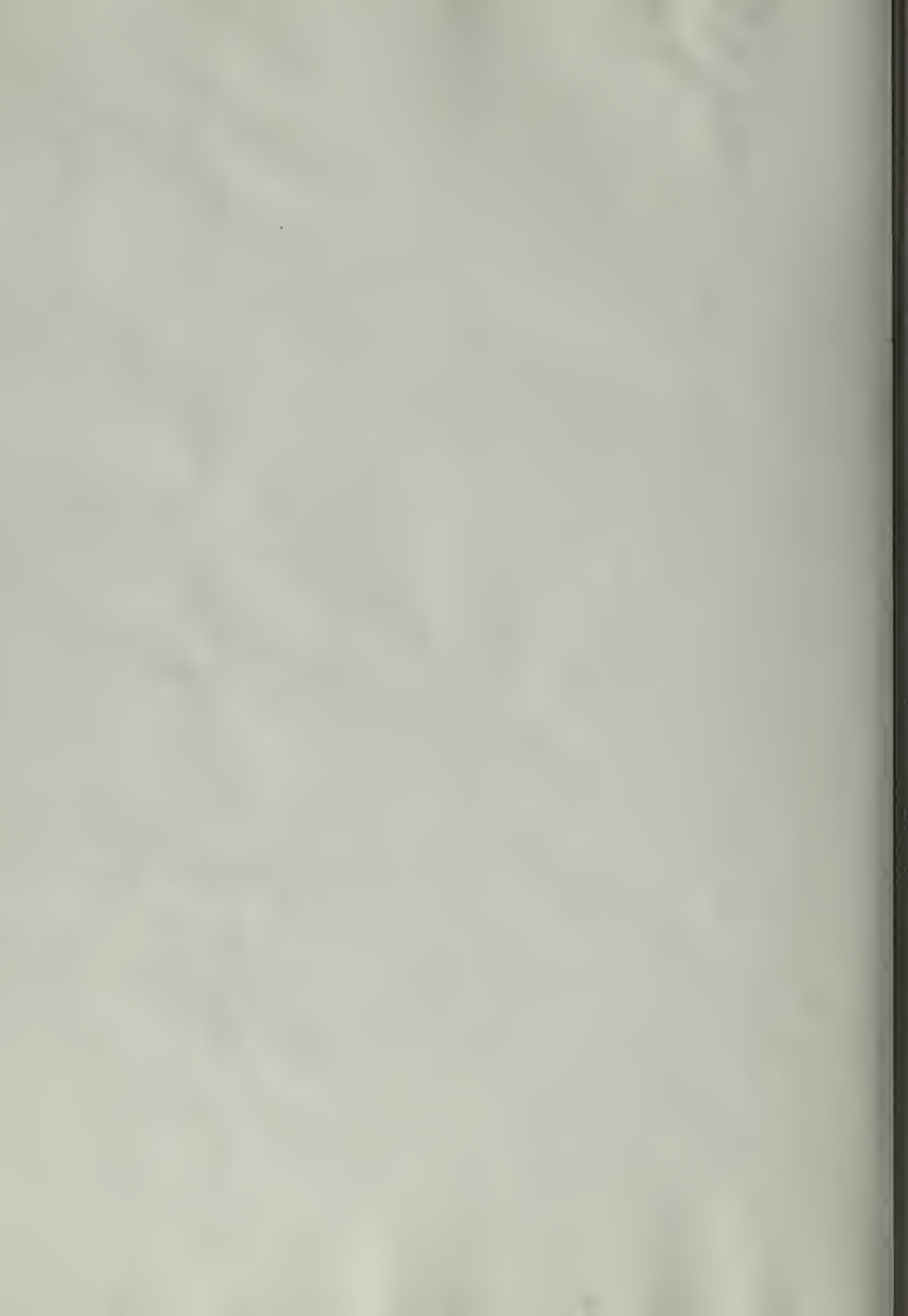


# SUMMARY OF ROD GAP TESTS

(IRRADIATED)

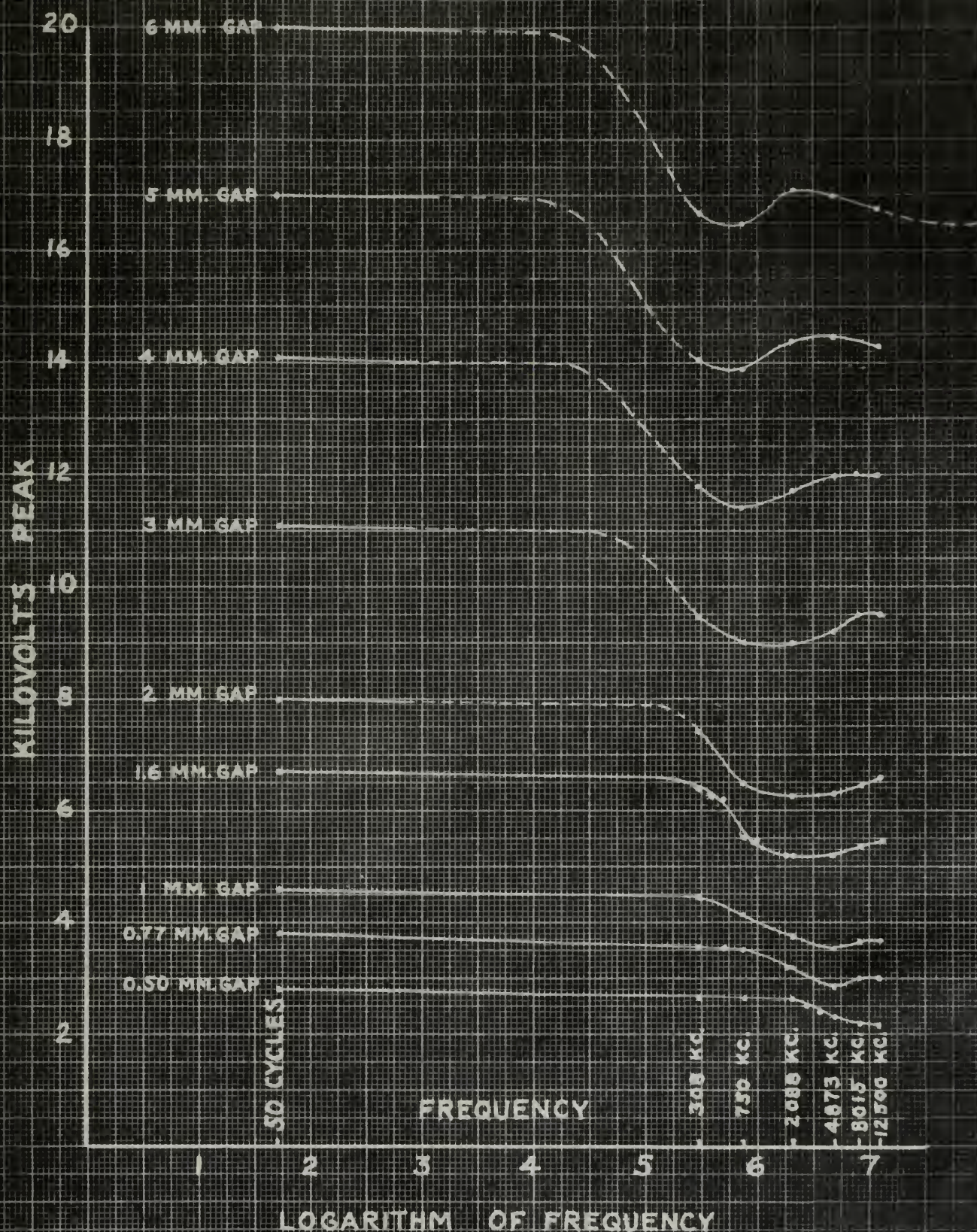




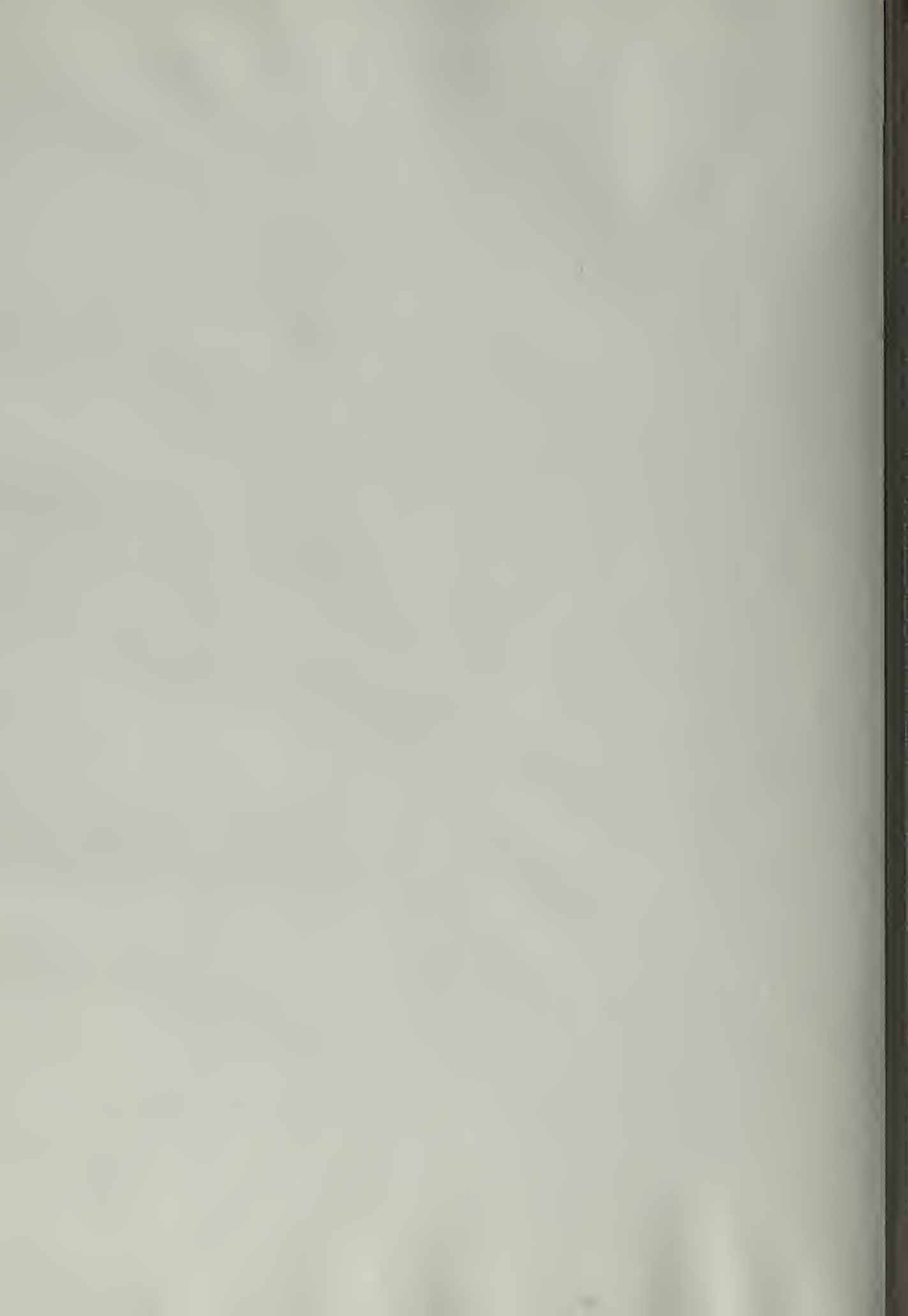


# SPHERE GAP SPARK-OVER VS FREQUENCY

2-CM SPHERES, IRRADIATED



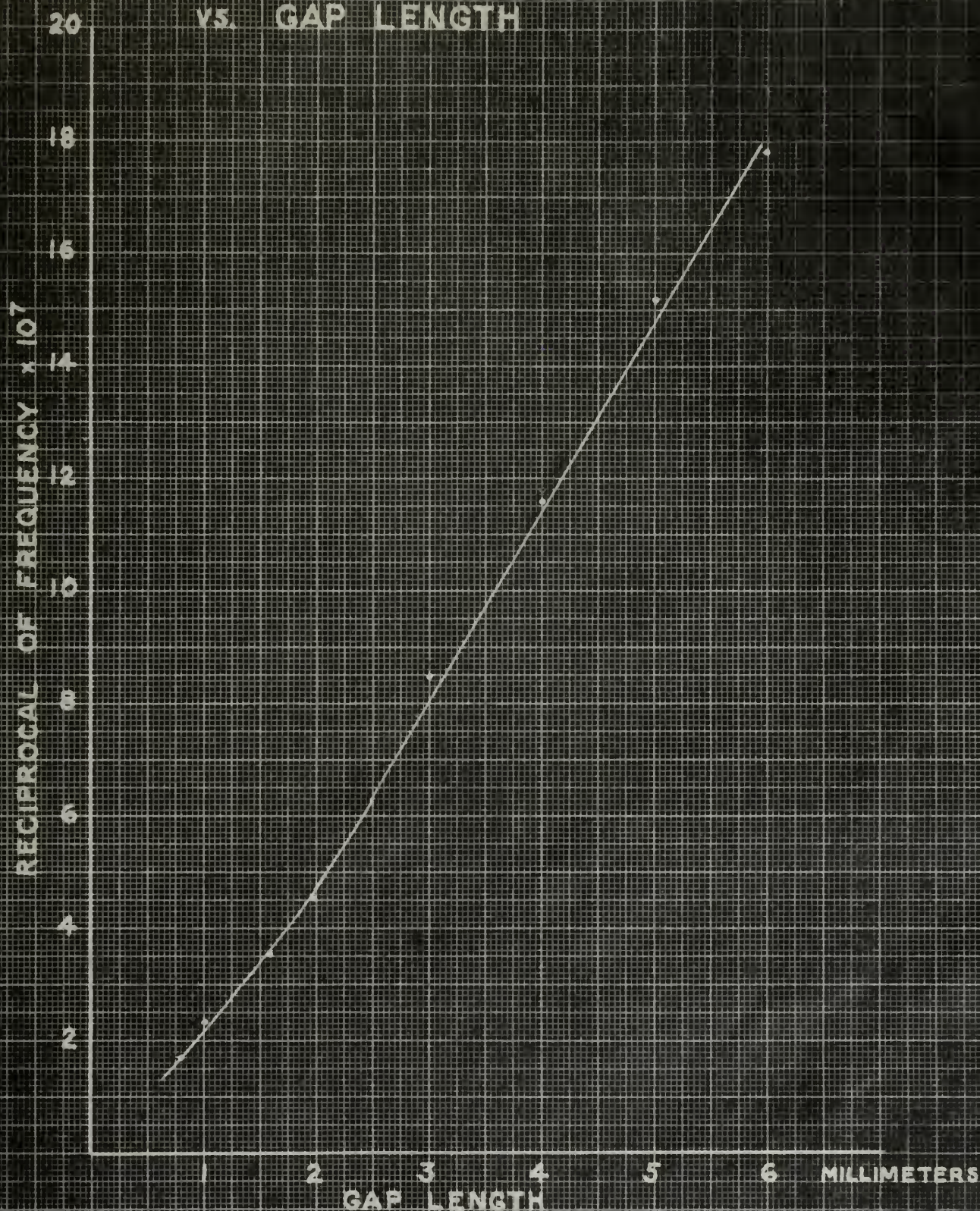


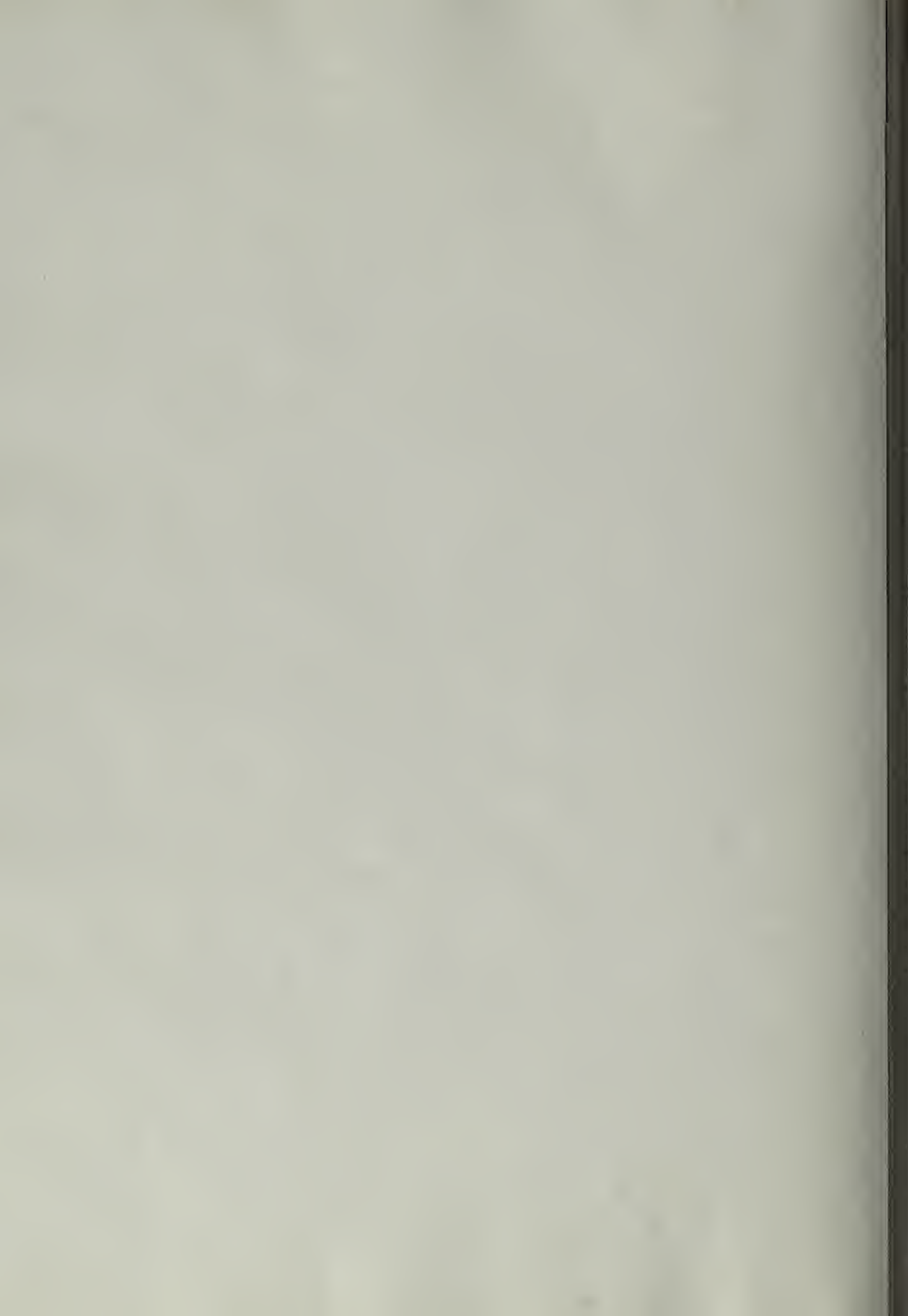




# RECIPROCAL OF FREQUENCY AT WHICH MINIMUM BREAKDOWN STRENGTH OCCURS

VS. GAP LENGTH







# DIELECTRIC STRENGTH OF AIR vs. FREQUENCY

## SURVEY OF PUBLISHED DATA

BIBLIOGRAPHY  
NUMBER

- 2.1 CM SPHERES, IRRADIATED. 5 MM GAP (17)
- ▽ 6.25 CM SPHERES, IRRADIATED. 5 MM GAP (3)
- 2 CM SPHERES, IRRADIATED. 3 MM GAP (6)
- 1.4 CM SPHERES, NOT IRRADIATED. 2 MM GAP (4)
- 5 CM SPHERES, NOT IRRADIATED. 2.5 MM GAP (5)
- ▽ PLANE PARALLEL GAPS, 0.1 TO 1.0 MM, IRRADIATED (22)
- △ WAVE GUIDE GAP, 15 MM. NOT IRRADIATED (24)
- △ WAVE GUIDE GAP, IRRADIATED (23)
- 2 CM SPHERES, IRRADIATED. 3 MM GAP (FROM DATA OF THIS REPORT)

KILOVOLTS PER CENTIMETER

FREQUENCY

50 CYCLES

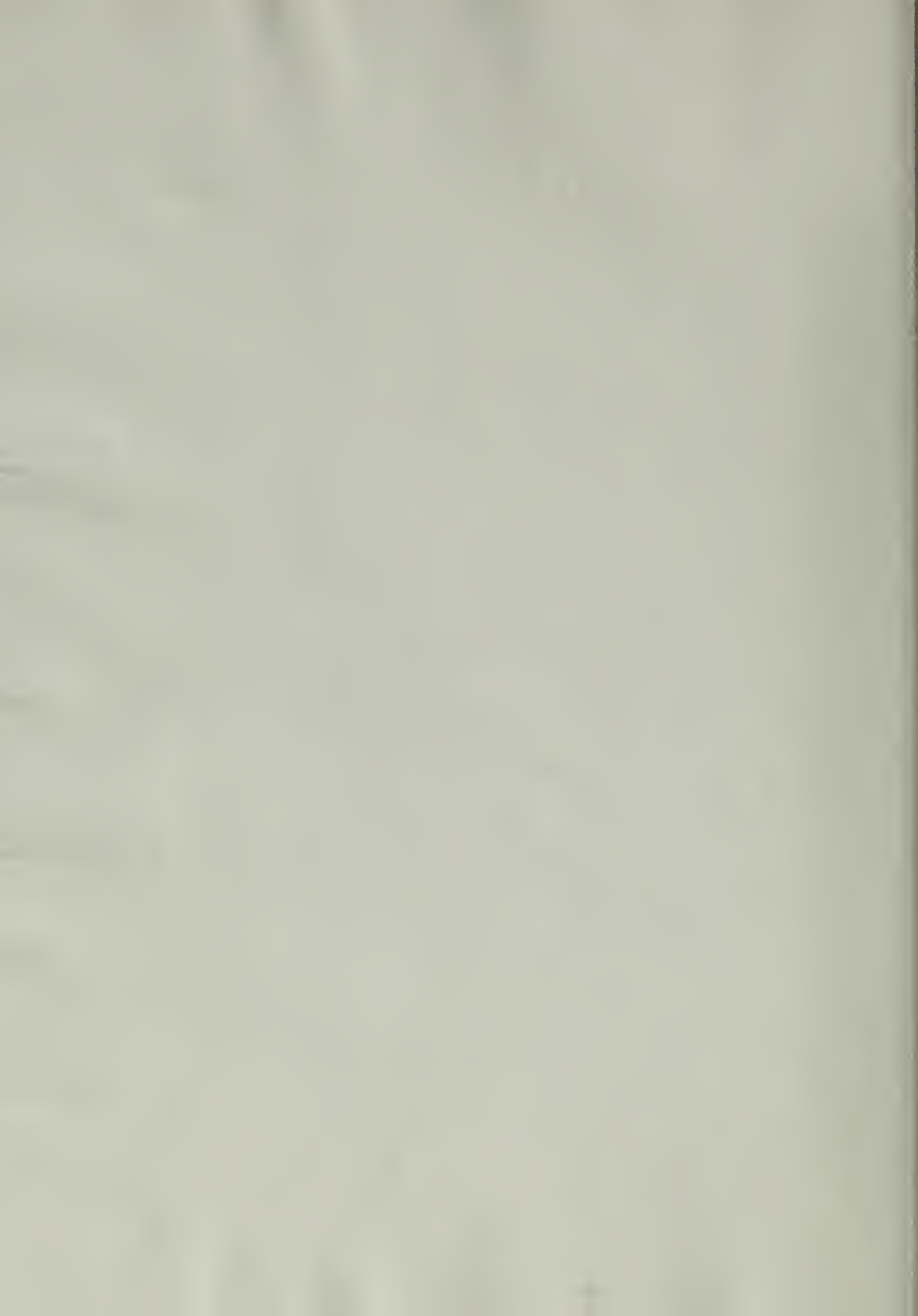
300 K.C.  
750 K.C.  
2088 K.C.  
4873 K.C.  
8015 K.C.  
12500 K.C.

100 M.C.  
300 M.C.

S BAND  
X BAND  
K BAND

LOGARITHM OF FREQUENCY





## CONCLUSIONS

The use of sphere gaps for the measurement of moderately high voltages at high frequencies, has been investigated and found to be quite practical in the ranges of frequency and voltage considered. In fact, a small sphere-gap, with controlled irradiation, is shown to be an accurate and extremely simple method for measuring these voltages. Data are presented for frequencies from 300 kilocycles to 12.5 megacycles, and for voltages up to about 20 kilovolts peak. The results overlap and are in general agreement with data which have been published in the lower part of this frequency range, - up to 1.8 megacycles -, and considerably extend this range into frequencies regarding which no comparable data are available.

In the course of the investigation, it was noted that the decrease of breakdown voltage with frequency was not a smooth function, but was more in the nature of a transition from one value for lower frequencies to a reduced value for higher frequencies. A theoretical consideration of this effect appears in the discussion of results, and an approximate value of ion mobility is deduced, based on the theory proposed and the observed data. The value of ion mobility is in good agreement with other published figures.

Definite minima were observed when spark-over voltages for fixed gap lengths were plotted against frequency. These are ascribed to ionic oscillation, and calculations are set





forth which serve to substantiate this theory. It is noted that the frequencies of these minima lie in the same range as published values for ionic resonance frequencies detected in the plasma of gaseous discharges.

The probability of a second set of minima, at frequencies much higher than those used in this study, is noted from the plotted results. It is suggested that these higher-frequency minima may be related to electronic oscillations.

Fourth, it is noted that the frequency of these events in the same room is related to the time between previous events. It is noted that the frequency of these events is related to the time between previous events.

The probability of a second set of events, if they also occur, is noted to be in this ratio. It is noted that the probability of a second set of events, if they also occur, is noted to be in this ratio.

Frequency of events may be related to statistical fluctuations. It is noted that the frequency of events may be related to statistical fluctuations. It is noted that the frequency of events may be related to statistical fluctuations.

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## APPENDIX A

## 1. Calculation of Optimum Breakdown Frequency for Air at Atmospheric Pressure.

The force on an electron in an alternating

field is  $F = e E \sin \omega t$ ,

where  $F$  is the force in dynes;

$e$  is the electronic charge, in e.s.u.;

$E$  is the peak value of the field strength in statvolts per centimeter;

$\omega$  is the frequency in radians per second and

$t$  is time in seconds.

The electron acceleration will be  $a = \frac{F}{m}$  where  $m$  is its mass in grams.

Taking  $E$  to be 90 statvolts per centimeter, which is slightly lower than the breakdown value for atmospheric air, and substituting well known values for  $e$  and  $m$ , gives

$$a = 4.77 \times 10^{19} \sin \omega t \text{ (cm/sec}^2\text{.)}$$

$$\text{Now velocity } v = \int a dt = - \frac{4.77 \times 10^{19}}{\omega} \cos \omega t \text{ (cm/sec)}$$

$$\text{and displacement } d = \int v dt = \frac{-4.77 \times 10^{19}}{\omega^2} \sin \omega t \text{ (cm.)}$$

maximum displacement occurs for  $\sin \omega t = -1$ , so the maximum displacement is  $\frac{4.77 \times 10^{19}}{\omega^2}$  (cm).

Now the mean-free path of an electron in atmospheric air is approximately  $5 \times 10^{-5}$  centimeters. Equating this to the displacement calculated above gives  $\frac{4.77 \times 10^{19}}{\omega^2} = 5 \times 10^{-5} \text{ (cm)}$



24. *in situ* polymerization of methyl methacrylate in methylalumoxane

June 1957 • Vol. 11, No. 11

It is noted that  $\frac{1}{n} \sum_{i=1}^n \mathbf{1}_{\{X_i \in A\}} \rightarrow \mathbb{P}(X \in A)$  as  $n \rightarrow \infty$  for any measurable set  $A$ .

Finally, I want to say the obvious: while the economy's all

[illegible]
$$\left( \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \frac{e^{-itx}}{t} dt \right) = \pi \delta(x)$$
$$(\text{and } \theta \text{ is a prime divisor of } \frac{f(1)}{f(0)} + \frac{f(2)}{f(0)} + \dots + \frac{f(n)}{f(0)}) \neq 0 \text{, then } \theta \text{ divides } f(0) \text{.}$$

എല്ലാത്തരം കർമ്മങ്ങൾക്കും പരമമായ പരിപാടിയാണ് അർച്ചന.

Hence  $\omega^2 = 10^{24}$  (approximately)

Or  $\omega = 10^{12}$  radians per second.

or frequency =  $\frac{\omega}{2\pi} = 10^{11}$  cycles per second (approximately)

This represents the order of magnitude of the frequency for optimum breakdown; or in other words, the frequency at which the dielectric strength of atmospheric air would be a minimum.

## 2. Calculation of Ion Mobility.

The drift velocity  $v$  of an ion in a gas, under the influence of an applied electric field  $X$ , is usually taken to be  $v = kX$ , where  $k$  is the ion mobility, expressed in centimeters-per-second per volts-per centimeter. Assuming that ions are formed at the peak of an impressed sinusoidal field, their subsequent velocity would then be  $v = k E \cos \omega t$ , where  $E$  is the peak field strength and  $\omega$  is  $2\pi$  times the frequency. During the next quarter-cycle, until the field diminishes to zero, the ion will move a dis-

$$\text{tance } x = \int_0^{\frac{\pi}{2}} v dt$$

$$\text{Or, } x = \int_0^{\frac{\pi}{2}} k E \cos \omega t dt = \frac{k E}{\omega} \text{ centimeters}$$

$$\text{hence } k = \frac{\omega x}{E} = \frac{2\pi f x}{E}$$

Now from the curves on page 38 it can be concluded that for a 1-millimeter gap, the ions were able to reach the surface of the electrode for frequencies below about 300 kilocycles.

$$W = \frac{1}{2} \int_{-\infty}^{\infty} \dot{\phi}^2 dx$$

$$W = \frac{1}{2} \int_{-\infty}^{\infty} \dot{\phi}^2 dx$$

$$W = \frac{1}{2} \int_{-\infty}^{\infty} \dot{\phi}^2 dx$$

This represents the energy of the system. For a system consisting of a set of particles, the energy is the sum of the kinetic energies of the particles and the potential energy of the system.

## 2. Conservation of Energy

The total energy  $E$  of a system is the sum of the kinetic energy  $K$  and the potential energy  $V$ . If the system is isolated, the total energy is conserved. This is expressed by the equation  $E = K + V = \text{constant}$ . For a system of particles, the kinetic energy is the sum of the kinetic energies of the particles, and the potential energy is the sum of the potential energies of the particles. The total energy is conserved if the system is isolated and the forces are conservative.

$$E = K + V = \text{constant}$$

$$E = K + V = \text{constant}$$

$$E = K + V = \text{constant}$$

The total energy of a system is conserved if the system is isolated and the forces are conservative. This is a fundamental principle of physics. For a system of particles, the total energy is the sum of the kinetic energies of the particles and the potential energy of the system. The total energy is conserved if the system is isolated and the forces are conservative.



Assuming that the ions must traverse approximately half the total gap,  $x$  is then 0.05 centimeter. Using for  $E$  a value of 30,000 volts per centimeter, which is approximately the spark-over level, gives

$$k = \frac{2\pi \times 3 \times 10^5 \times 0.05}{30,000} = 3 \text{ cm/sec/volt/cm (approximately)}$$

...the ...

$$\frac{(1.73 \times 10^3 \text{ mol}) (8.314 \text{ J/mol}\cdot\text{K})}{(0.001 \text{ m}^3)} = 1.44 \times 10^7 \text{ J/m}^3$$

APPENDIX B

TABULATED DATA



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## TESTS ON 6.25 -cm. SPHERES AT 308 KILOCYCLES

Barometer 75.10 cm, temperature 25°C.

GAP LENGTH (millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
6.25	18260	17800
"	18130	18000
"	17920	18100
"	17920	18000
"	18350	18100
5.37	15400	14800
"	15300	15000
"	15400	15100
"	15300	15000
"	15400	15000
4.83	13700	13600
"	13700	13700
"	13800	13600
"	13700	13600
"	13600	13600
4.01	12200	11800
"	12200	11800
"	12300	11700
"	12100	11800
"	12200	11800
3.04	9850	9500
"	9730	9450
"	9560	9450
"	9730	9450
"	9770	9450
2.28	7880	8000
"	8130	7900
"	8210	7900
"	8530	7900
"	8000	7900
1.63	7030	6480
"	6750	6480
"	6880	6400
"	7000	6480
"	6960	6480
0.86	4300	3900
"	4250	3900
"	4330	3850
"	4220	3900
"	4330	3900

# STATE OF TEXAS - DEPARTMENT OF AGRICULTURE

ANNUAL REPORT FOR THE YEAR 1900

GRAIN - WHEAT	GRAIN - CORN	GRAIN - OATS
(In bushels)	(In bushels)	(In bushels)
1900	1900	1900
1901	1901	1901
1902	1902	1902
1903	1903	1903
1904	1904	1904
1905	1905	1905
1906	1906	1906
1907	1907	1907
1908	1908	1908
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1911	1911	1911
1912	1912	1912
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1991	1991	1991
1992	1992	1992
1993	1993	1993
1994	1994	1994
1995	1995	1995
1996	1996	1996
1997	1997	1997
1998	1998	1998
1999	1999	1999
2000	2000	2000



TESTS ON 2-cm. SPHERES AT 308 KILOCYCLES

Barometer 75.93 cm, Temperature 24°C.

GAP LENGTH (millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
6.32	17800	17500
"	17800	17400
"	18000	17400
"	18200	17500
"	18100	17400
5.73	16300	16100
"	16400	16100
"	16300	16100
"	16300	16100
"	16600	16100
4.72	13600	13400
"	13800	13400
"	13800	13400
"	13800	13300
"	13800	13300
4.07	11900	11900
"	11900	11900
"	11900	11900
"	11900	11900
"	12100	19000
3.56	11000	10800
"	10900	10600
"	11200	10700
"	11000	10700
"	11000	10700
2.35	8430	8150
"	8500	8200
"	8750	8200
"	8750	8150
"	8750	8100
1.82	7620	7100
"	7820	6900
"	7500	6900
"	7300	7000
"	7500	7000

Page	Page	Page
1	2	3
4	5	6
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748	749	750
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760	761	762
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847	848	849
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853	854	855
856	857	858
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862	863	864
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868	869	870
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889	890	891
892	893	894
895	896	897
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949	950	951
952	953	954
955	956	957
958	959	960
961	962	963
964	965	966
967	968	969
970	971	972
973	974	975
976	977	978
979	980	981
982	983	984
985	986	987
988	989	990
991	992	993
994	995	996
997	998	999
1000	1001	1002

TESTS ON 2-cm. SPHERES AT 308 KILOCYCLES  
(Cont'd)

GAP LENGTH (millimeters)	SPARK-OVER VOLTAGE (Peak Volts, Corrected)	
	Not irradiated	Irradiated
1.12	5900	4800
"	4900	4800
"	5400	4750
"	5200	4700
"	5300	4700
1.65	6900	6500
"	6700	6470
"	7000	6470
"	7050	6470
"	7100	6440



# STATE OF NEW YORK IN SENATE

REPORT OF THE  
COMMISSIONER OF THE LAND OFFICE  
IN RESPONSE TO A RESOLUTION PASSED BY THE SENATE  
MARCH 1, 1894

LANDS BELONGING TO THE STATE	LANDS BELONGING TO THE STATE	LANDS BELONGING TO THE STATE
1. 100,000	1. 100,000	1. 100,000
2. 200,000	2. 200,000	2. 200,000
3. 300,000	3. 300,000	3. 300,000
4. 400,000	4. 400,000	4. 400,000
5. 500,000	5. 500,000	5. 500,000
6. 600,000	6. 600,000	6. 600,000
7. 700,000	7. 700,000	7. 700,000
8. 800,000	8. 800,000	8. 800,000
9. 900,000	9. 900,000	9. 900,000
10. 1,000,000	10. 1,000,000	10. 1,000,000
11. 1,100,000	11. 1,100,000	11. 1,100,000
12. 1,200,000	12. 1,200,000	12. 1,200,000
13. 1,300,000	13. 1,300,000	13. 1,300,000
14. 1,400,000	14. 1,400,000	14. 1,400,000
15. 1,500,000	15. 1,500,000	15. 1,500,000
16. 1,600,000	16. 1,600,000	16. 1,600,000
17. 1,700,000	17. 1,700,000	17. 1,700,000
18. 1,800,000	18. 1,800,000	18. 1,800,000
19. 1,900,000	19. 1,900,000	19. 1,900,000
20. 2,000,000	20. 2,000,000	20. 2,000,000
21. 2,100,000	21. 2,100,000	21. 2,100,000
22. 2,200,000	22. 2,200,000	22. 2,200,000
23. 2,300,000	23. 2,300,000	23. 2,300,000
24. 2,400,000	24. 2,400,000	24. 2,400,000
25. 2,500,000	25. 2,500,000	25. 2,500,000
26. 2,600,000	26. 2,600,000	26. 2,600,000
27. 2,700,000	27. 2,700,000	27. 2,700,000
28. 2,800,000	28. 2,800,000	28. 2,800,000
29. 2,900,000	29. 2,900,000	29. 2,900,000
30. 3,000,000	30. 3,000,000	30. 3,000,000
31. 3,100,000	31. 3,100,000	31. 3,100,000
32. 3,200,000	32. 3,200,000	32. 3,200,000
33. 3,300,000	33. 3,300,000	33. 3,300,000
34. 3,400,000	34. 3,400,000	34. 3,400,000
35. 3,500,000	35. 3,500,000	35. 3,500,000
36. 3,600,000	36. 3,600,000	36. 3,600,000
37. 3,700,000	37. 3,700,000	37. 3,700,000
38. 3,800,000	38. 3,800,000	38. 3,800,000
39. 3,900,000	39. 3,900,000	39. 3,900,000
40. 4,000,000	40. 4,000,000	40. 4,000,000
41. 4,100,000	41. 4,100,000	41. 4,100,000
42. 4,200,000	42. 4,200,000	42. 4,200,000
43. 4,300,000	43. 4,300,000	43. 4,300,000
44. 4,400,000	44. 4,400,000	44. 4,400,000
45. 4,500,000	45. 4,500,000	45. 4,500,000
46. 4,600,000	46. 4,600,000	46. 4,600,000
47. 4,700,000	47. 4,700,000	47. 4,700,000
48. 4,800,000	48. 4,800,000	48. 4,800,000
49. 4,900,000	49. 4,900,000	49. 4,900,000
50. 5,000,000	50. 5,000,000	50. 5,000,000
51. 5,100,000	51. 5,100,000	51. 5,100,000
52. 5,200,000	52. 5,200,000	52. 5,200,000
53. 5,300,000	53. 5,300,000	53. 5,300,000
54. 5,400,000	54. 5,400,000	54. 5,400,000
55. 5,500,000	55. 5,500,000	55. 5,500,000
56. 5,600,000	56. 5,600,000	56. 5,600,000
57. 5,700,000	57. 5,700,000	57. 5,700,000
58. 5,800,000	58. 5,800,000	58. 5,800,000
59. 5,900,000	59. 5,900,000	59. 5,900,000
60. 6,000,000	60. 6,000,000	60. 6,000,000
61. 6,100,000	61. 6,100,000	61. 6,100,000
62. 6,200,000	62. 6,200,000	62. 6,200,000
63. 6,300,000	63. 6,300,000	63. 6,300,000
64. 6,400,000	64. 6,400,000	64. 6,400,000
65. 6,500,000	65. 6,500,000	65. 6,500,000
66. 6,600,000	66. 6,600,000	66. 6,600,000
67. 6,700,000	67. 6,700,000	67. 6,700,000
68. 6,800,000	68. 6,800,000	68. 6,800,000
69. 6,900,000	69. 6,900,000	69. 6,900,000
70. 7,000,000	70. 7,000,000	70. 7,000,000
71. 7,100,000	71. 7,100,000	71. 7,100,000
72. 7,200,000	72. 7,200,000	72. 7,200,000
73. 7,300,000	73. 7,300,000	73. 7,300,000
74. 7,400,000	74. 7,400,000	74. 7,400,000
75. 7,500,000	75. 7,500,000	75. 7,500,000
76. 7,600,000	76. 7,600,000	76. 7,600,000
77. 7,700,000	77. 7,700,000	77. 7,700,000
78. 7,800,000	78. 7,800,000	78. 7,800,000
79. 7,900,000	79. 7,900,000	79. 7,900,000
80. 8,000,000	80. 8,000,000	80. 8,000,000
81. 8,100,000	81. 8,100,000	81. 8,100,000
82. 8,200,000	82. 8,200,000	82. 8,200,000
83. 8,300,000	83. 8,300,000	83. 8,300,000
84. 8,400,000	84. 8,400,000	84. 8,400,000
85. 8,500,000	85. 8,500,000	85. 8,500,000
86. 8,600,000	86. 8,600,000	86. 8,600,000
87. 8,700,000	87. 8,700,000	87. 8,700,000
88. 8,800,000	88. 8,800,000	88. 8,800,000
89. 8,900,000	89. 8,900,000	89. 8,900,000
90. 9,000,000	90. 9,000,000	90. 9,000,000
91. 9,100,000	91. 9,100,000	91. 9,100,000
92. 9,200,000	92. 9,200,000	92. 9,200,000
93. 9,300,000	93. 9,300,000	93. 9,300,000
94. 9,400,000	94. 9,400,000	94. 9,400,000
95. 9,500,000	95. 9,500,000	95. 9,500,000
96. 9,600,000	96. 9,600,000	96. 9,600,000
97. 9,700,000	97. 9,700,000	97. 9,700,000
98. 9,800,000	98. 9,800,000	98. 9,800,000
99. 9,900,000	99. 9,900,000	99. 9,900,000
100. 10,000,000	100. 10,000,000	100. 10,000,000

TESTS ON 6.25 cm. SPHERES AT 750 KILOCYCLES

Barometer 75.00 cm., Temperature 27°.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not Irradiated	Irradiated
6.45	17900	17800
"	17900	17800
"	18200	17800
"	18000	17800
"	17850	17900
4.81	13700	13600
"	13700	13540
"	13700	13540
"	13700	13540
"	13600	13540
3.49	10300	10200
"	10500	10150
"	10500	10220
"	10300	10220
"	10300	10220
2.48	7700	7600
"	8000	7700
"	8100	7750
"	8000	7700
"	8160	7700
2.08	6800	6700
"	7000	6650
"	7050	6650
"	7100	6650
"	7050	6650
1.63	6000	5750
"	6000	5700
"	6000	5700
"	5900	5650
"	5950	5650
1.07	4640	4500
"	4600	4450
"	4760	4450
"	4960	4450
"	4960	4450

Continued from Table 1, page 1

Year	Area (sq. miles)	Population (1960)
1960	1,000	100,000
1959	1,000	100,000
1958	1,000	100,000
1957	1,000	100,000
1956	1,000	100,000
1955	1,000	100,000
1954	1,000	100,000
1953	1,000	100,000
1952	1,000	100,000
1951	1,000	100,000
1950	1,000	100,000
1949	1,000	100,000
1948	1,000	100,000
1947	1,000	100,000
1946	1,000	100,000
1945	1,000	100,000
1944	1,000	100,000
1943	1,000	100,000
1942	1,000	100,000
1941	1,000	100,000
1940	1,000	100,000
1939	1,000	100,000
1938	1,000	100,000
1937	1,000	100,000
1936	1,000	100,000
1935	1,000	100,000
1934	1,000	100,000
1933	1,000	100,000
1932	1,000	100,000
1931	1,000	100,000
1930	1,000	100,000
1929	1,000	100,000
1928	1,000	100,000
1927	1,000	100,000
1926	1,000	100,000
1925	1,000	100,000
1924	1,000	100,000
1923	1,000	100,000
1922	1,000	100,000
1921	1,000	100,000
1920	1,000	100,000



## TEST ON 2-cm. SPHERES AT 750 KILOCYCLES

Barometer 74.93 cm., Temperature 27°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not Irradiated	Irradiated
6.45	17900	17600
"	18300	17600
"	17900	17600
"	17900	17700
"	18300	17700
4.82	14500	13400
"	14100	13300
"	13600	13500
"	14000	13400
"	13600	13400
3.50	11100	10400
"	11200	10200
"	10800	10300
"	11000	10300
"	11200	10300
2.50	8300	7800
"	8600	7760
"	8600	7760
"	8750	7700
"	8750	7760
1.64	5820	5650
"	5950	5600
"	6760	5670
"	6480	5670
"	6480	5670
1.10	4820	4650
"	4980	4650
"	4980	4650
"	4900	4650
"	5150	4650

TABLE OF THE  
 RESULTS OF THE INVESTIGATION  
 INTO THE CAUSE OF THE  
 DEATH OF THE  
 PRESIDENT OF THE UNITED STATES

DATE OF THE INVESTIGATION	NAME OF THE PERSON INVESTIGATED	RESULT OF THE INVESTIGATION
1898	1898	1898
1899	1899	1899
1900	1900	1900
1901	1901	1901
1902	1902	1902
1903	1903	1903
1904	1904	1904
1905	1905	1905
1906	1906	1906
1907	1907	1907
1908	1908	1908
1909	1909	1909
1910	1910	1910
1911	1911	1911
1912	1912	1912
1913	1913	1913
1914	1914	1914
1915	1915	1915
1916	1916	1916
1917	1917	1917
1918	1918	1918
1919	1919	1919
1920	1920	1920
1921	1921	1921
1922	1922	1922
1923	1923	1923
1924	1924	1924
1925	1925	1925
1926	1926	1926
1927	1927	1927
1928	1928	1928
1929	1929	1929
1930	1930	1930
1931	1931	1931
1932	1932	1932
1933	1933	1933
1934	1934	1934
1935	1935	1935
1936	1936	1936
1937	1937	1937
1938	1938	1938
1939	1939	1939
1940	1940	1940
1941	1941	1941
1942	1942	1942
1943	1943	1943
1944	1944	1944
1945	1945	1945
1946	1946	1946
1947	1947	1947
1948	1948	1948
1949	1949	1949
1950	1950	1950
1951	1951	1951
1952	1952	1952
1953	1953	1953
1954	1954	1954
1955	1955	1955
1956	1956	1956
1957	1957	1957
1958	1958	1958
1959	1959	1959
1960	1960	1960
1961	1961	1961
1962	1962	1962
1963	1963	1963
1964	1964	1964
1965	1965	1965
1966	1966	1966
1967	1967	1967
1968	1968	1968
1969	1969	1969
1970	1970	1970
1971	1971	1971
1972	1972	1972
1973	1973	1973
1974	1974	1974
1975	1975	1975
1976	1976	1976
1977	1977	1977
1978	1978	1978
1979	1979	1979
1980	1980	1980
1981	1981	1981
1982	1982	1982
1983	1983	1983
1984	1984	1984
1985	1985	1985
1986	1986	1986
1987	1987	1987
1988	1988	1988
1989	1989	1989
1990	1990	1990
1991	1991	1991
1992	1992	1992
1993	1993	1993
1994	1994	1994
1995	1995	1995
1996	1996	1996
1997	1997	1997
1998	1998	1998
1999	1999	1999
2000	2000	2000

TESTS ON 6.25-cm. SPHERES AT 2088 KILOCYCLES

Barometer 76.20 cm., Temperature 28°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, Corrected)	
	Not irradiated,	Irradiated
5.93	17650	16800
"	16600	17000
"	17100	16800
"	17000	16200
"	17000	17000
4.83	14000	14000
"	13700	13700
"	14000	13800
"	13500	14000
"	13600	13900
3.80	11100	11400
"	11100	11300
"	11200	11400
"	11200	11200
"	11200	11300
2.86	8800	8460
"	8600	8460
"	8600	8570
"	8550	8570
"	8400	8500
1.62	5220	5250
"	5220	5200
"	5300	5150
"	5300	5200
"	5260	5200
1.11	4250	3950
"	4030	3900
"	4030	3950
"	4030	3950
"	4030	3900





# TESTS ON 2-cm. SPHERES AT 2088 KILOCYCLES

Barometer 76.94 cm., Temperature 25°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
6.00	16900	17100
"	17250	17200
"	17150	16900
"	17250	17000
"	17150	17100
4.42	13000	12800
"	12800	13000
"	13100	13100
"	12900	13200
"	13000	13100
3.77	11050	11000
"	11250	11000
"	11250	11100
"	11360	11100
"	11360	11200
2.72	8500	8450
"	8470	8380
"	8550	8380
"	8650	8380
"	8470	8380
1.63	5250	5300
"	5250	5300
"	5360	5300
"	5400	5350
"	5400	5450
0.64	3550	2970
"	3350	2970
"	3150	3000
"	3550	2970
"	3150	2970

• *Staphylococcus aureus* and *Staphylococcus epidermidis*



# TESTS ON 2-cm. SPHERES AT 4873 KILOCYCLES

Barometer 76.15 cm., Temperature 27 °C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
6.45	18300	18300
"	18400	18100
"	18500	18000
"	18400	18100
"	18300	18200
4.83	14150	14200
"	14250	14100
"	14150	14200
"	14450	14100
"	14350	14100
3.43	10800	10600
"	10800	10500
"	10800	10500
"	10700	10500
"	10700	10500
2.49	7800	7700
"	7760	7700
"	7760	7650
"	7760	7650
"	7760	7700
1.53	5160	5020
"	5080	5020
"	5210	4980
"	5450	4980
"	5250	4980



TESTS ON 2-cm. SPHERES AT 8015 KILOCYCLES

Barometer 77.20 cm., Temperature 28°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
4.15	12500	12400
"	12500	12500
"	12500	12500
"	12400	12500
"	12500	12500
3.06	9350	9500
"	9570	9600
"	9350	9600
"	9350	9500
"	9460	9600
2.10	6860	6800
"	6860	6800
"	6830	6740
"	6900	6800
"	6860	6800
1.13	4180	4000
"	4180	4000
"	4060	4000
"	4100	3960
"	4100	4000



TABLE 1. SUMMARY OF DATA FOR THE STUDY

TABLE 2. SUMMARY OF DATA FOR THE STUDY

STATION DATA (1960-1965)		STATION DATA (1960-1965)
Station Name	Station Number	Station Name
0001	0001	0001
0002	0002	0002
0003	0003	0003
0004	0004	0004
0005	0005	0005
0006	0006	0006
0007	0007	0007
0008	0008	0008
0009	0009	0009
0010	0010	0010
0011	0011	0011
0012	0012	0012
0013	0013	0013
0014	0014	0014
0015	0015	0015
0016	0016	0016
0017	0017	0017
0018	0018	0018
0019	0019	0019
0020	0020	0020
0021	0021	0021
0022	0022	0022
0023	0023	0023
0024	0024	0024
0025	0025	0025
0026	0026	0026
0027	0027	0027
0028	0028	0028
0029	0029	0029
0030	0030	0030
0031	0031	0031
0032	0032	0032
0033	0033	0033
0034	0034	0034
0035	0035	0035
0036	0036	0036
0037	0037	0037
0038	0038	0038
0039	0039	0039
0040	0040	0040
0041	0041	0041
0042	0042	0042
0043	0043	0043
0044	0044	0044
0045	0045	0045
0046	0046	0046
0047	0047	0047
0048	0048	0048
0049	0049	0049
0050	0050	0050
0051	0051	0051
0052	0052	0052
0053	0053	0053
0054	0054	0054
0055	0055	0055
0056	0056	0056
0057	0057	0057
0058	0058	0058
0059	0059	0059
0060	0060	0060
0061	0061	0061
0062	0062	0062
0063	0063	0063
0064	0064	0064
0065	0065	0065
0066	0066	0066
0067	0067	0067
0068	0068	0068
0069	0069	0069
0070	0070	0070
0071	0071	0071
0072	0072	0072
0073	0073	0073
0074	0074	0074
0075	0075	0075
0076	0076	0076
0077	0077	0077
0078	0078	0078
0079	0079	0079
0080	0080	0080
0081	0081	0081
0082	0082	0082
0083	0083	0083
0084	0084	0084
0085	0085	0085
0086	0086	0086
0087	0087	0087
0088	0088	0088
0089	0089	0089
0090	0090	0090
0091	0091	0091
0092	0092	0092
0093	0093	0093
0094	0094	0094
0095	0095	0095
0096	0096	0096
0097	0097	0097
0098	0098	0098
0099	0099	0099
0100	0100	0100

TESTS ON 2-cm. SPHERES AT 12500 KILOCYCLES

Barometer 75.96 cm., Temperature 28°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
6.47	18000	17800
"	18200	17800
"	18200	17800
"	18100	17800
"	17800	17800
4.83	14150	13950
"	13700	13950
"	13900	13850
"	13900	13850
"	14150	13950
3.52	10700	10750
"	10700	10750
"	10700	10750
"	10800	10750
"	10900	10750
2.50	8240	8050
"	8360	8150
"	8360	8050
"	8330	8050
"	8240	8150
1.12	4030	4050
"	4120	4000
"	4130	4050
"	4160	4000
"	4120	4050

TABLE 1  
 SUMMARY OF DATA FOR THE  
 YEAR 1964  
 (Continued)

Description of Item		Value
1. Total	1964	100.0
	1963	95.0
	1962	90.0
	1961	85.0
	1960	80.0
2. Subtotal	1964	85.0
	1963	80.0
	1962	75.0
	1961	70.0
	1960	65.0
3. Another Subtotal	1964	70.0
	1963	65.0
	1962	60.0
	1961	55.0
	1960	50.0
4. Final Subtotal	1964	55.0
	1963	50.0
	1962	45.0
	1961	40.0
	1960	35.0



TESTS ON 2-cm. SPHERES (IRRADIATED)

Barometer 76.20 cm., Temperature 25°C.

GAP LENGTH 0.50 Millimeters

FREQUENCY	SPARK -OVER VOLTAGE (CORRECTED)	FREQUENCY	SPARK-OVER VOLTAGE (CORRECTED)
2088 KC	2600	300 KC	2600
"	2640	"	2600
"	2600	"	2600
"	2600	"	2600
"	2600	"	2600
2 847 KC	2500	750 KC	2650
"	2500	"	2650
"	2500	"	2600
"	2500	"	2600
"	2500	"	2600
3550 KC	2350		
"	2400		
"	2400		
"	2400		
"	2350		
4873 KC	2250		
"	2250		
"	2300		
"	2300		
"	2350		
8015 KC	2250		
"	2200		
"	2200		
"	2200		
"	2150		
12500 KC	2100		
"	2100		
"	2100		
"	2100		
"	2100		

TABLE 1. - *Continued*

WATER TEMPERATURES (°C) AT 0.5 METER DEPTH

STATION	DATE	TIME	TEMPERATURE (°C)
1000	10/10	0800	20.0
1000	10/10	0900	20.0
1000	10/10	1000	20.0
1000	10/10	1100	20.0
1000	10/10	1200	20.0
1000	10/10	1300	20.0
1000	10/10	1400	20.0
1000	10/10	1500	20.0
1000	10/10	1600	20.0
1000	10/10	1700	20.0
1000	10/10	1800	20.0
1000	10/10	1900	20.0
1000	10/10	2000	20.0
1000	10/10	2100	20.0
1000	10/10	2200	20.0
1000	10/10	2300	20.0
1000	10/10	2400	20.0
1000	10/10	2500	20.0
1000	10/10	2600	20.0
1000	10/10	2700	20.0
1000	10/10	2800	20.0
1000	10/10	2900	20.0
1000	10/10	3000	20.0
1000	10/10	3100	20.0
1000	10/10	3200	20.0
1000	10/10	3300	20.0
1000	10/10	3400	20.0
1000	10/10	3500	20.0
1000	10/10	3600	20.0
1000	10/10	3700	20.0
1000	10/10	3800	20.0
1000	10/10	3900	20.0
1000	10/10	4000	20.0
1000	10/10	4100	20.0
1000	10/10	4200	20.0
1000	10/10	4300	20.0
1000	10/10	4400	20.0
1000	10/10	4500	20.0
1000	10/10	4600	20.0
1000	10/10	4700	20.0
1000	10/10	4800	20.0
1000	10/10	4900	20.0
1000	10/10	5000	20.0
1000	10/10	5100	20.0
1000	10/10	5200	20.0
1000	10/10	5300	20.0
1000	10/10	5400	20.0
1000	10/10	5500	20.0
1000	10/10	5600	20.0
1000	10/10	5700	20.0
1000	10/10	5800	20.0
1000	10/10	5900	20.0
1000	10/10	6000	20.0
1000	10/10	6100	20.0
1000	10/10	6200	20.0
1000	10/10	6300	20.0
1000	10/10	6400	20.0
1000	10/10	6500	20.0
1000	10/10	6600	20.0
1000	10/10	6700	20.0
1000	10/10	6800	20.0
1000	10/10	6900	20.0
1000	10/10	7000	20.0
1000	10/10	7100	20.0
1000	10/10	7200	20.0
1000	10/10	7300	20.0
1000	10/10	7400	20.0
1000	10/10	7500	20.0
1000	10/10	7600	20.0
1000	10/10	7700	20.0
1000	10/10	7800	20.0
1000	10/10	7900	20.0
1000	10/10	8000	20.0
1000	10/10	8100	20.0
1000	10/10	8200	20.0
1000	10/10	8300	20.0
1000	10/10	8400	20.0
1000	10/10	8500	20.0
1000	10/10	8600	20.0
1000	10/10	8700	20.0
1000	10/10	8800	20.0
1000	10/10	8900	20.0
1000	10/10	9000	20.0
1000	10/10	9100	20.0
1000	10/10	9200	20.0
1000	10/10	9300	20.0
1000	10/10	9400	20.0
1000	10/10	9500	20.0
1000	10/10	9600	20.0
1000	10/10	9700	20.0
1000	10/10	9800	20.0
1000	10/10	9900	20.0
1000	10/10	10000	20.0

TESTS ON 2-cm. SPHERES (IRRADIATED)

Barometer 75.97 cm., Temperature 27°C.

GAP LENGTH 0.77 Millimeter

FREQUENCY	SPARK-OVER VOLTAGE (CORRECTED)
300 KC	3600
"	3550
"	3550
"	3550
"	3550
500 KC	3550
"	3600
"	3550
"	3550
"	3600
750 KC	3500
"	3500
"	3500
"	3500
"	3500
2000 KC	3200
"	3200
"	3200
"	3200
"	3200

GAP LENGTH 1.60 millimeter

FREQUENCY	SPARK-OVER VOLTAGE (CORRECTED)
300 KC	6400
"	6400
400 KC	6300
"	6300
500 KC	6300
"	6250
"	6200
"	6250
"	6200
1000 KC	5500
"	5500
"	5500
"	5500
"	5450
2000 KC	5300
"	5150
"	5200
"	5150
"	5150





## TESTS ON ROD GAP AT 2088 KILOCYCLES

Barometer 76.20 cm., Temperature 28°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
25.00	19000	14600
"	16300	14600
"	17300	14500
"	16500	14800
"	16900	14700
19.20	15000	13700
"	14750	13900
"	15700	13900
"	15100	13900
"	15500	13900
14.37	13900	12400
"	15300	12400
"	15000	12500
"	13700	12500
"	14300	12600
9.54	12300	11000
"	11900	11100
"	13000	11000
"	12500	11100
"	12600	11000
4.83	7800	8400
"	8500	8500
"	9020	8500
"	9430	8500
"	9210	8450
2.50	5330	5900
"	5940	5950
"	6060	5900
"	6350	5900
"	6380	5800

Submitted: 07/20/00; Accepted: 08/20/00

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099
1990	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099



# TESTS ON ROD GAP AT 4873 KILOCYCLES

Barometer 76.00 cm., Temperature 27°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
23.10	14250	13600
"	14350	13700
"	13800	13700
"	14500	13200
"	15000	13300
19.20	12250	12700
"	12700	12700
"	13900	12700
"	13900	12700
"	14100	12700
9.70	11200	10600
"	11400	10500
"	10700	10600
"	11500	10600
"	11300	10600
4.85	7300	7900
"	7700	8100
"	7800	8200
"	8200	8200
"	8200	8200
2.15	4260	4700
"	4260	5030
"	4230	5630
"	4430	5750
"	4300	5800
"	5640	5870
"	5830	5800



TESTS ON ROD GAP AT 8015 KILOCYCLES

Barometer 76.04 cm., Temperature 26°C.

GAP LENGTH (Millimeters)	SPARK-OVER VOLTAGE (Peak Volts, corrected)	
	Not irradiated	Irradiated
11.65	12100	11200
"	12100	11500
"	12600	11500
"	12600	11500
"	12600	11500
9.55	10300	10500
"	12000	10500
"	12200	10700
"	11200	10500
"	11500	10500
4.88	8400	8700
"	8600	8600
"	8600	8500
"	8700	8400
"	8800	8400
2.85	6900	6600
"	7100	6700
"	7700	6500
"	7900	6700
"	7800	6700
1.63	3300	4500
"	3750	4600
"	4000	4700
"	4300	5000
"	4600	5000





# CALIBRATION OF VACUUM -TUBE VOLTMETER

Cylindrical Capacitance  $C = 0.632 \mu\mu F.$

Frequency (Kilocycles)	Capacitance Current (Milliamperes)	Calculated Peak Volts	Voltmeter Reading
2760	37.0	4760	1.20
"	24.5	3160	0.80
"	30.5	3930	0.99
"	36.5	4700	1.99
2482	26.4	3770	0.95
"	34.8	4980	1.26
"	42.2	6030	1.54
"	45.2	6460	1.64
"	52.5	7510	1.88
"	53.5	7650	1.90
"	49.2	7030	1.75

Cylindrical Capacitance  $C = 0.885 \mu\mu F.$

2482	56.4	5750	1.44
"	69.5	7090	1.75
"	71.8	7320	1.82
"	74.0	7550	1.88
"	44.3	4520	1.14
"	36.5	3720	0.95
"	27.5	2800	0.72
"	47.2	4810	1.19

Cylindrical Capacitance  $C = 0.434 \mu\mu F.$

2185	24.5	5800	1.42
"	28.2	6680	1.60
"	56.2	8580	2.07
"	44.4	10530	2.55
"	44.4	10530	1.00
"	50.5	12000	1.15
"	51.0	12100	1.18
"	59.8	14200	1.36
"	65.0	15400	1.48
"	69.4	16400	1.57
"	75.2	17800	1.72
"	36.5	8650	0.81
"	32.5	7700	0.72
5089	59.5	6070	1.50





CALIBRATION OF VACUUM-TUBE VOLTMETER  
(Cont'd)

Cylindrical Capacitance  $C = 1.760 \mu\mu F.$

Frequency (Kilocycles)	Capacitance Current (Milliamperes)	Calculated Peak Volts	Voltmeter Reading
308	27.0	11200	2.66
"	24.0	9960	2.40
"	24.5	10170	2.44
"	24.5	10170	0.96
"	24.0	9960	2.42
"	19.0	7880	1.28
"	31.5	13100	1.22
"	36.5	15100	1.43
"	20.0	8300	2.00
"	38.2	15800	1.50
"	42.3	17500	1.67
"	45.2	18700	1.78
"	31.0	12900	1.20
"	46.0	19100	1.83
"	46.2	19150	1.81
"	46.8	19400	1.84
"	46.4	19200	1.83
"	46.2	19150	1.81
"	46.0	19100	1.80
"	43.5	18000	1.73
"	42.6	17700	1.69
"	41.4	17200	1.64
"	39.8	16500	1.57
"	38.5	16000	1.52
500	33.0	8450	2.07
"	39.0	9980	2.45
"	33.8	8650	2.10
"	40.7	10400	2.53
"	22.8	5840	1.45
"	38.6	9880	0.94
"	44.4	11350	1.08
"	49.8	12750	1.22
"	55.2	14100	1.35
"	59.7	15280	1.48
"	63.4	16200	1.54



CALIBRATION OF VACUUM-TUBE VOLTMETER  
(Cont'd)

Cylindrical Capacitance  $C = 1.760 \mu\mu F.$

Frequency (Kilocycles)	Capacitance Current (Milliamperes)	Calculated Peak Volts	Voltmeter Reading
900	49.0	6950	1.70
"	65.0	9220	2.25
"	32.0	4540	1.10
"	32.7	4640	1.13
"	39.0	5530	1.35
"	74.7	10600	2.62
"	74.4	10540	2.60
"	74.0	10480	1.01
"	52.2	7400	1.80
2000	67.0	4280	1.05
"	73.0	4660	1.14



# THE UNIVERSITY OF CHICAGO

CHICAGO, ILL., U.S.A.

Name	Address	City	State
Mr. J. Edgar Hoover	Federal Bureau of Investigation	Washington, D.C.	District of Columbia
Mr. W. A. Rorer	The Rorer Company	Chicago, Ill.	Illinois
Mr. C. D. Jackson	The Jackson Company	Chicago, Ill.	Illinois

DIRECT-CURRENT CALIBRATION OF THERMOCOUPLE

Western Electric Co. Thermocouple No. 21136  
rated 5 ohms, 75 milliamperes, connected to  
General Electric Co. microammeter No. 1112211

Heater Current (Milliamperes)	Meter Reading (0-3 scale)
20.76	0.145
28.93	0.280
35.42	0.410
42.63	0.590
48.51	0.730
53.30	0.855
59.61	1.016
65.35	1.170
70.77	1.317
74.72	1.420
53.47	0.867
37.53	0.470
25.10	0.226
15.70	0.100
67.80	1.243
64.10	1.142





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MEMORANDUM

The writer wishes to recommend the appointment of the  
Judge and the Honorable Mr. Justice of the Peace  
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## VITA

Charles Benjamin Oler, born 1907, received his primary and secondary education in the schools of New York and New Jersey. Graduated from the University of Pennsylvania in 1927 as B.S. in E.E., he worked for two years with General Electric Co. in Schenectady and Pittsfield. On a fellowship at the University of Pennsylvania he received an M.S. in E.E. in 1930, and then took up a career in teaching, which has included 3 years at Massachusetts Institute of Technology, 4 years at The College of The City of New York, 1 year at Swarthmore College, and 4 years at the U. S. Naval Post-graduate School, where he is at present an Associate Professor. During interim periods he was for 2 years with Gibbs and Hill Co, consulting engineers, and for 4 years during the war served as a Naval officer. Graduate studies undertaken subsequent to the M.S. include courses at Massachusetts Institute of Technology, University of Pennsylvania, Columbia University, and The Johns Hopkins University.



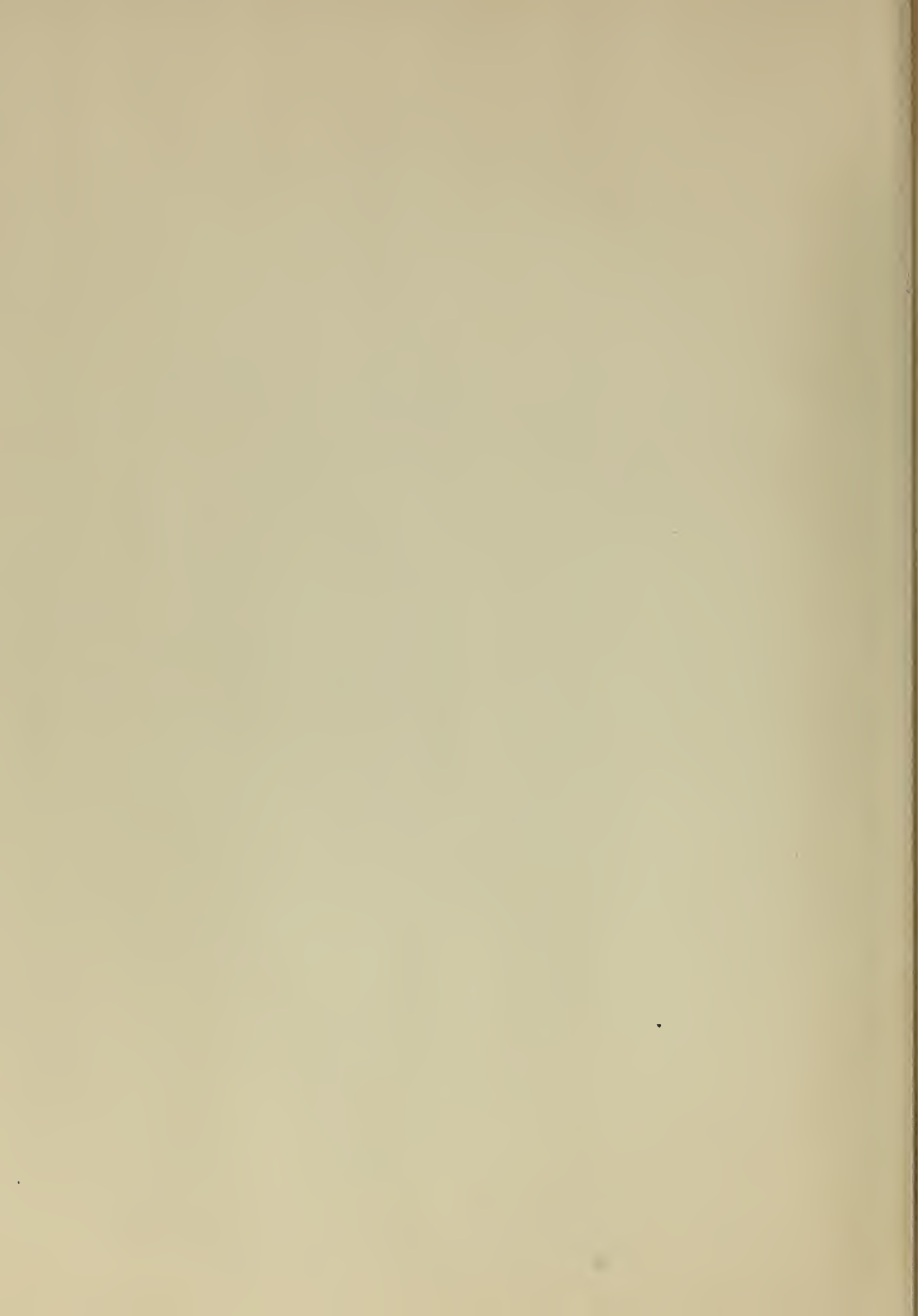
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